Robot Technology Development

Perception, User Interfaces and Architecture

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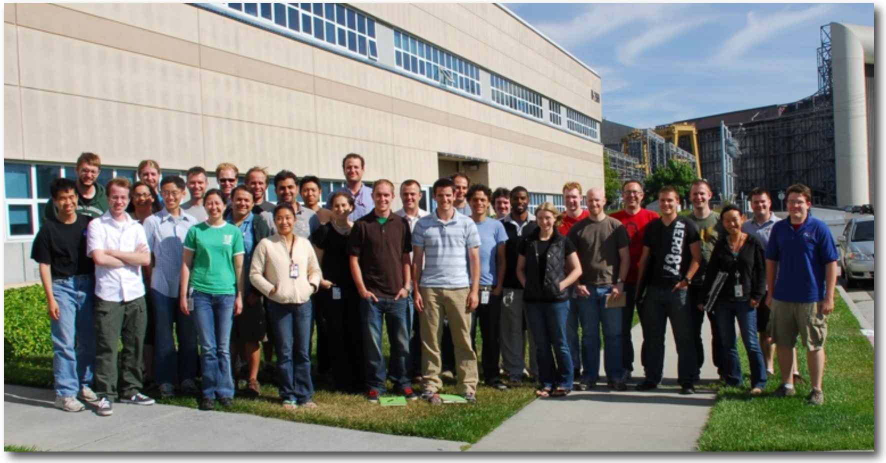
Intelligent Robotics Group (IRG)

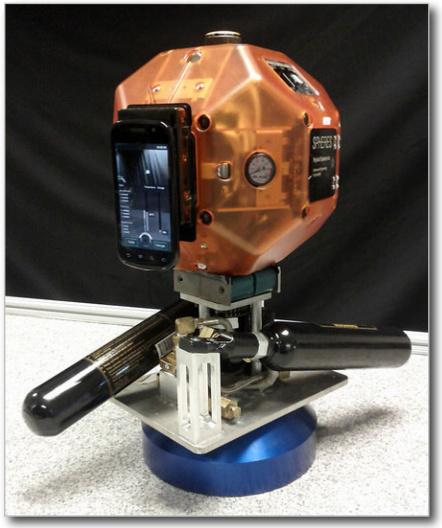
Overview

- 31 researchers (14 Ph.D.’s)
- 20+ summer interns yearly
- 75% NASA work (HEOMD, STMD, SMD)
- 25% reimbursable (Google, etc.)
- SBIR / STTR (10 current proj.)

Research themes

- **Automated planetary mapping**
  - Base maps & terrain models
  - Geospatial data systems
- **Robots for human explorers**
  - Improve efficiency & productivity
  - Pre-cursor & “follow-up” work
- **Public service**
  - Disaster response & outreach





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IRG Collaborations (2010-2013)

Academic

- The Robotics Institute
- Leland Stanford Junior University
- Massachusetts Institute of Technology
- Arizona State University
- University of Idaho
- École Polytechnique Fédérale de Lausanne
- Humboldt-Universität zu Berlin
- ETH Eidgenössische Technische Hochschule Zürich / Swiss Federal Institute of Technology Zurich
- SETI Institute
- KAIST Korea Advanced Institute of Science and Technology 한국과학기술원

Commercial

- Google
- Microsoft Research
- Aurora Flight Sciences
- Microcosm Inc
- Stottler Henke Smarter Software Solutions
- Energid
- Honeybee Robotics
- Optech
- TRAClabs
- ProtoInnovations
- PRCI

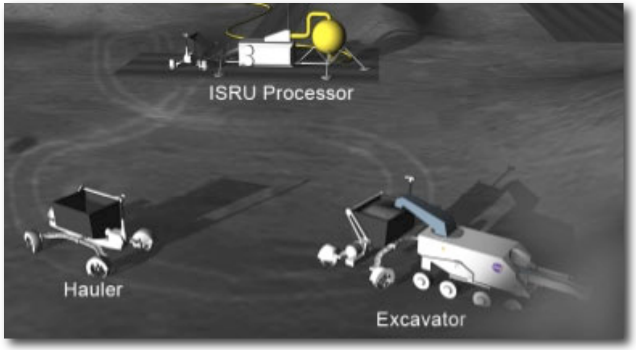
Government

- SPAWAR
- CAL FIRE
- California Task Force 3 U.S.&R. Urban Search and Rescue
- USGS science for a changing world

Robotics for Human Exploration

Purpose

- Increase human productivity
- Improve mission planning & execution
- Transfer **some** tasks to robots (tedious, repetitive, long-duration)



Before Crew

- Recon (scouting) & prospecting
- Site prep, deploy equipment, etc.

Supporting Crew

- Inspection, mobile camera, etc.
- Heavy transport & mobility

After Crew

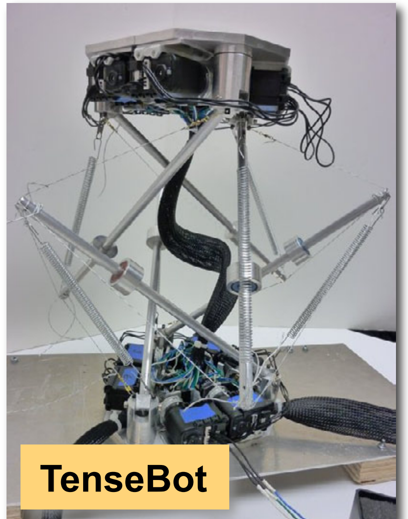
- Follow-up & close-out work
- Site survey, supplementary tasks, etc.

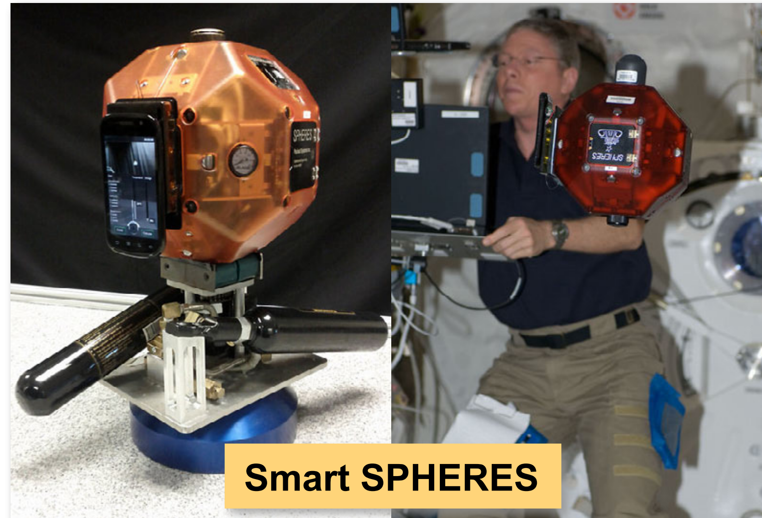
Robots


K10 mini


K10

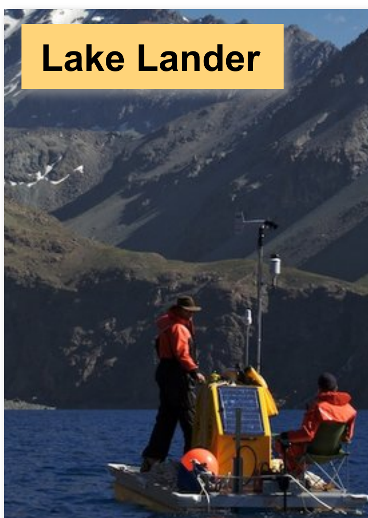

KREX


TenseBot


Smart SPHERES

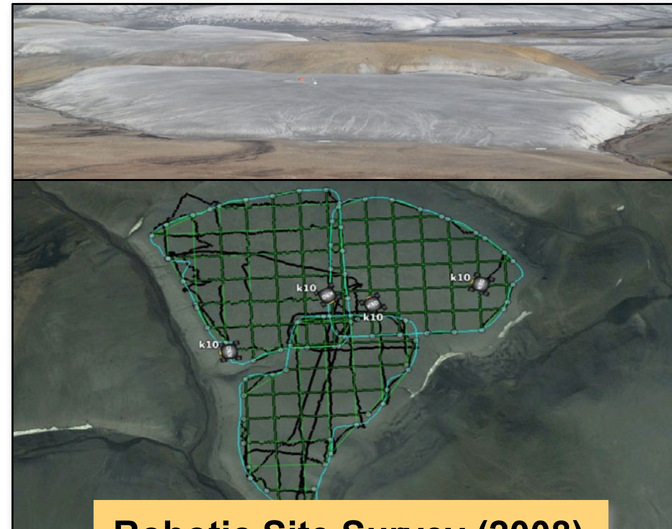

Modular Arm


GigaPan

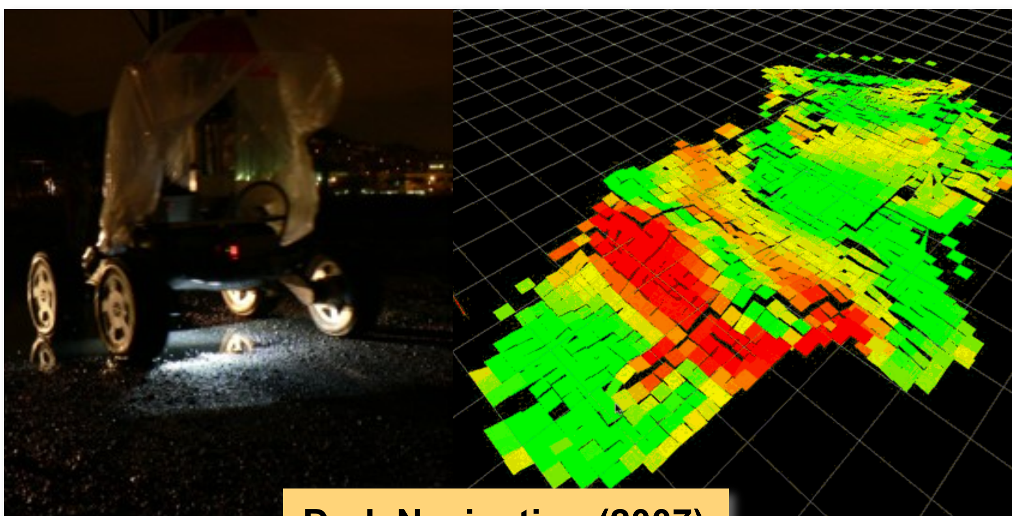

Lake Lander

Perception

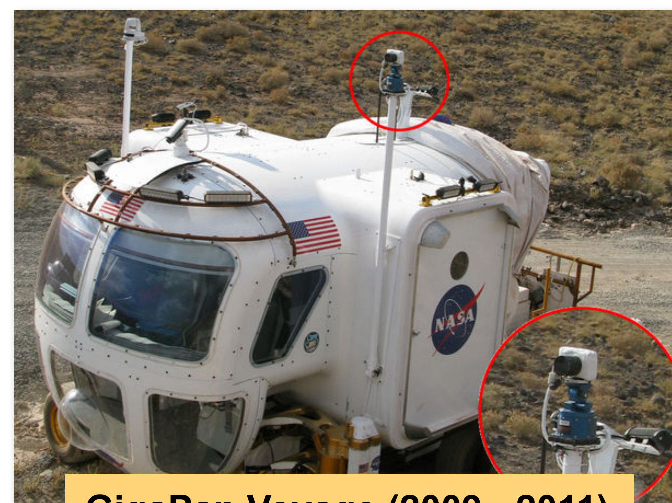
High Dynamic Range inspection (2006)



Robotic Site Survey (2008)

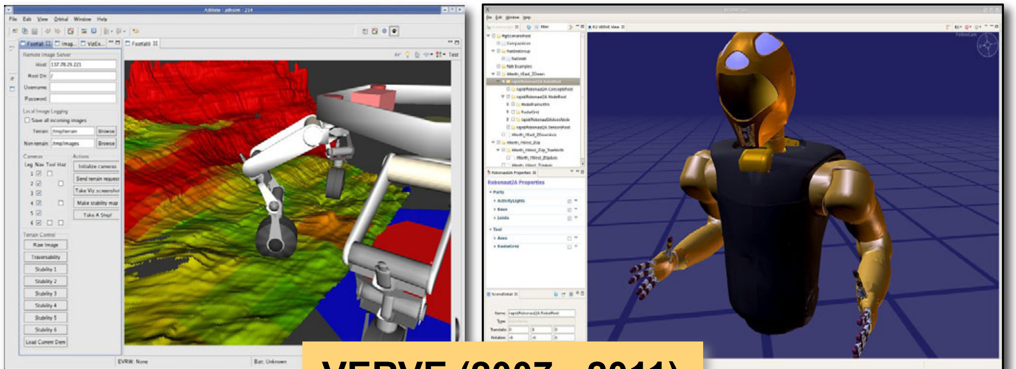


Dark Navigation (2007)

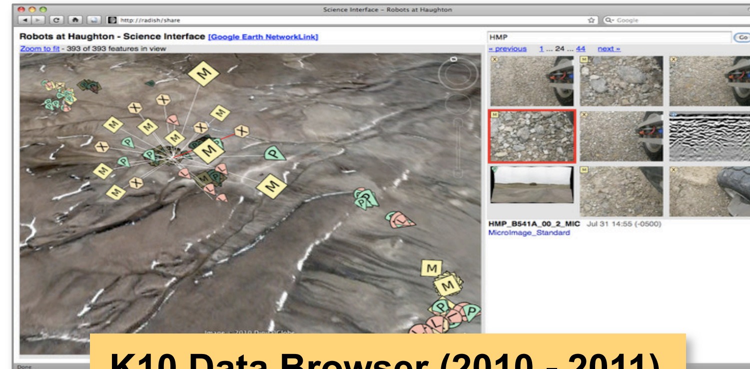


GigaPan Voyage (2009 - 2011)

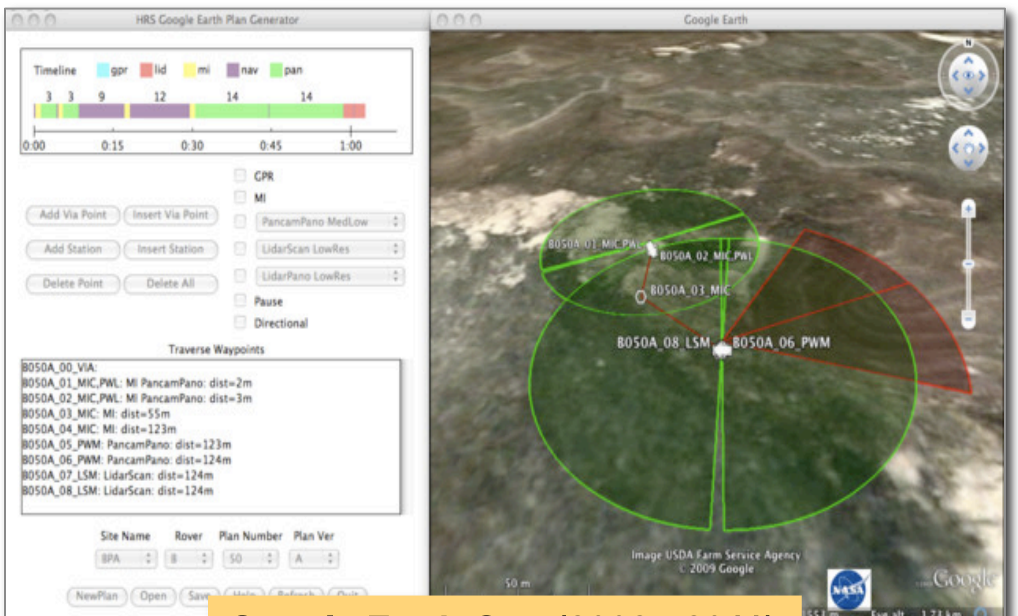
User Interfaces



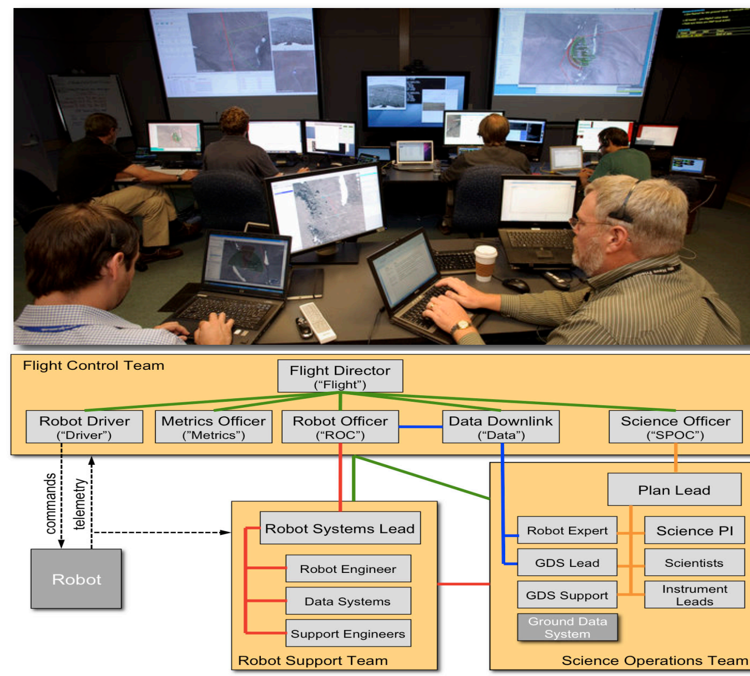
VERVE (2007 - 2011)



K10 Data Browser (2010 - 2011)

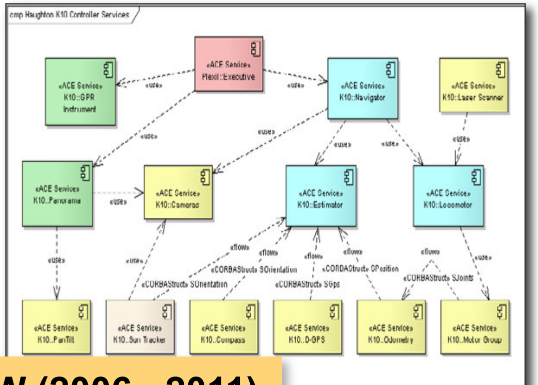


Google Earth Ops (2008 - 2011)

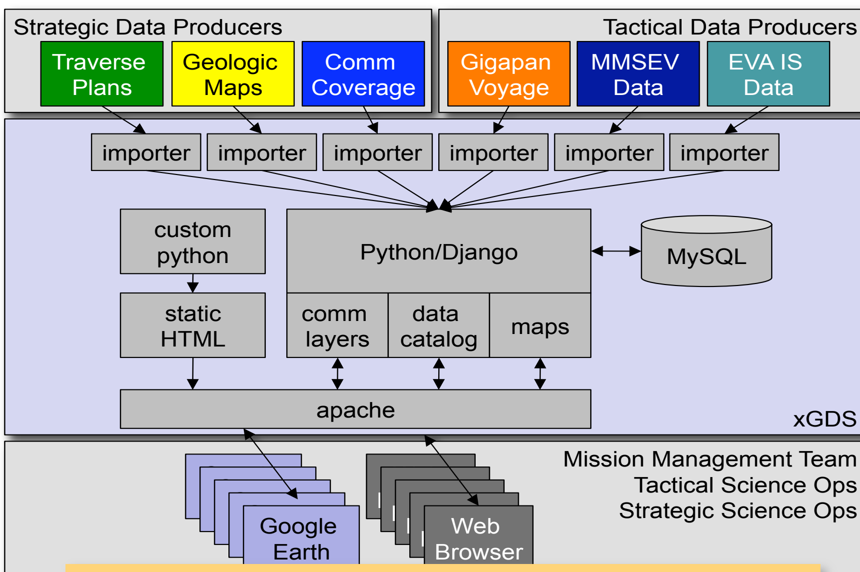


Interactive Ground Control (2008 - 2010)

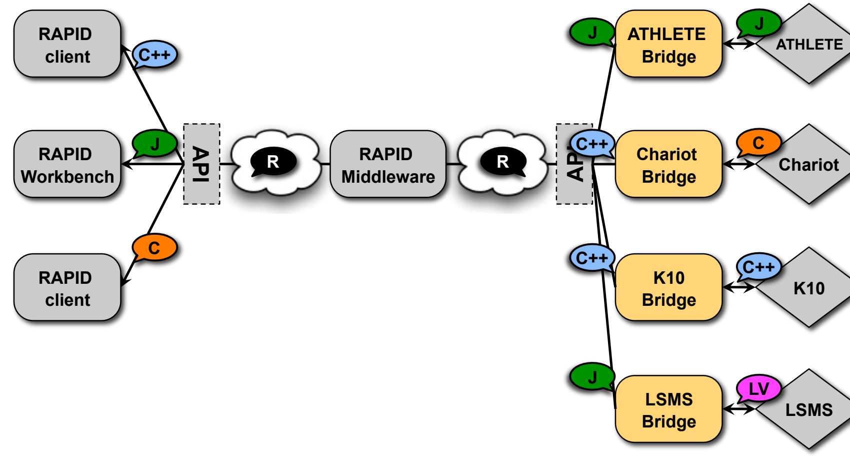
Architecture



RoverSW (2006 - 2011)



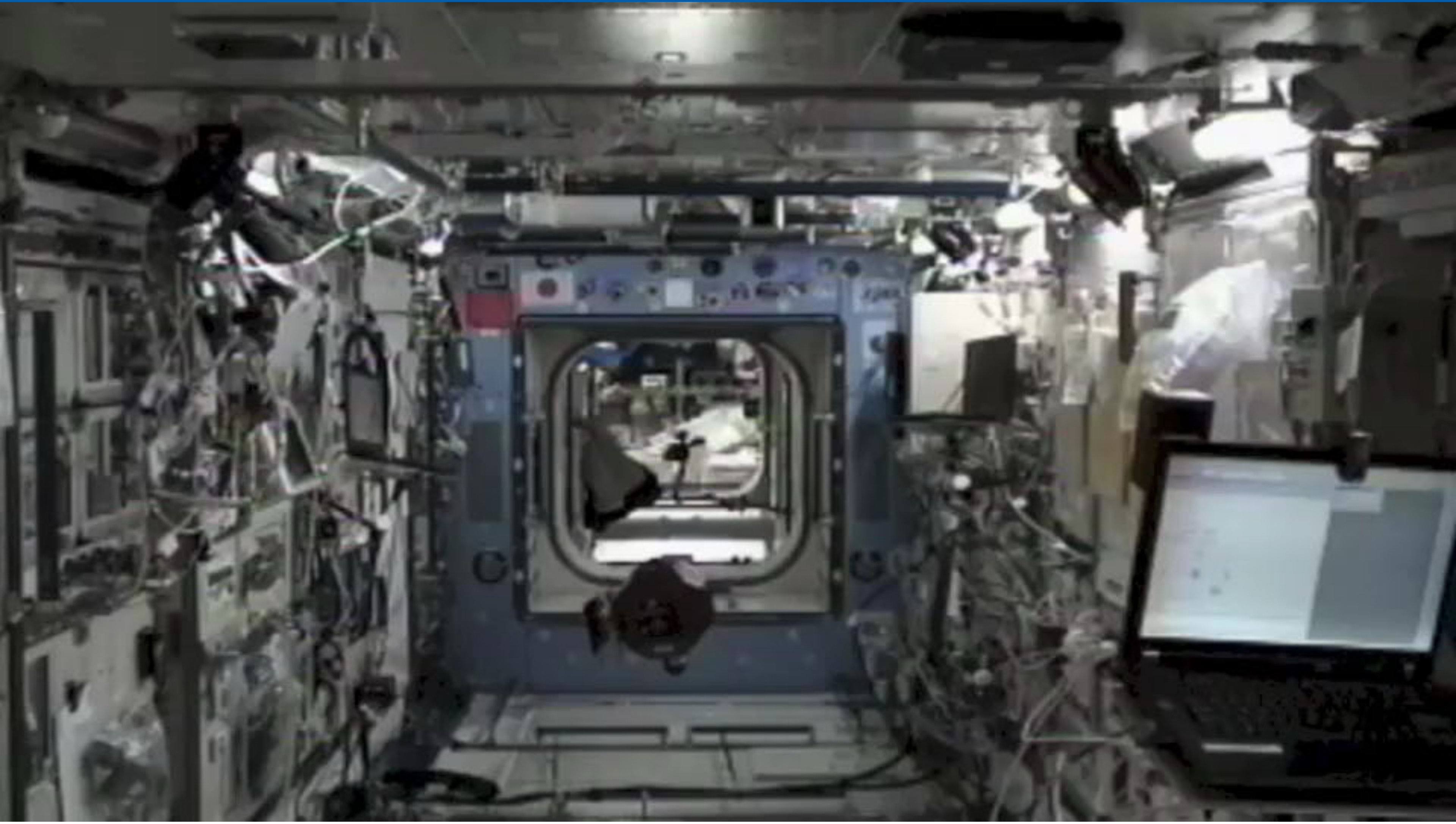
xGDS: Exploration Ground Data System (2009 - 2011)



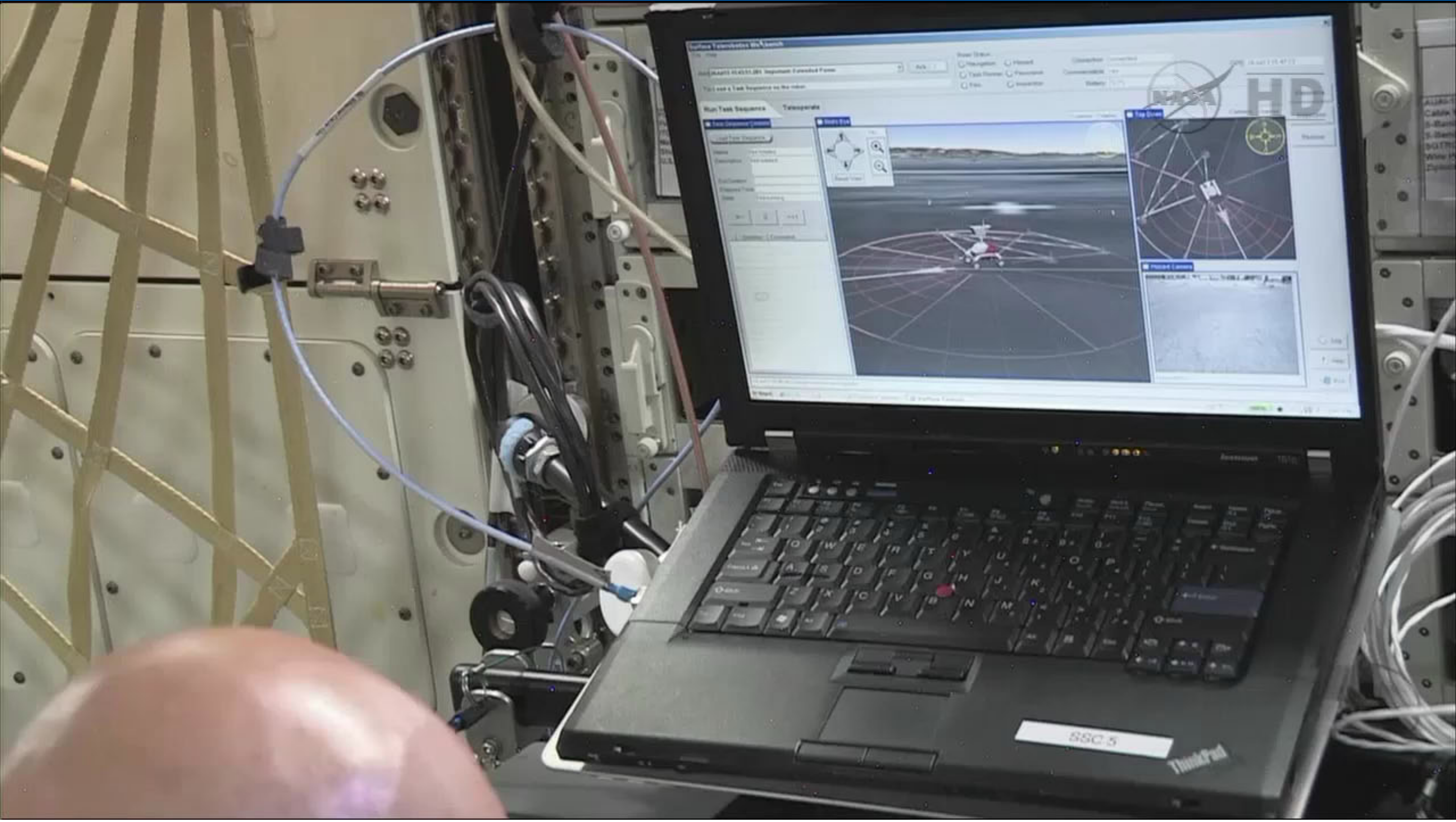
RAPID (2009 - 2011)

K10 Robot at Haughton Crater, Canada

SmartSPHERES on ISS



K10 Remotely Operated from ISS



Mars in Google Earth

Explore Mars in 3D

- Released Feb. 2, 2009
- Co-developed with Google
- NASA Ames created content & processing scripts

Content

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

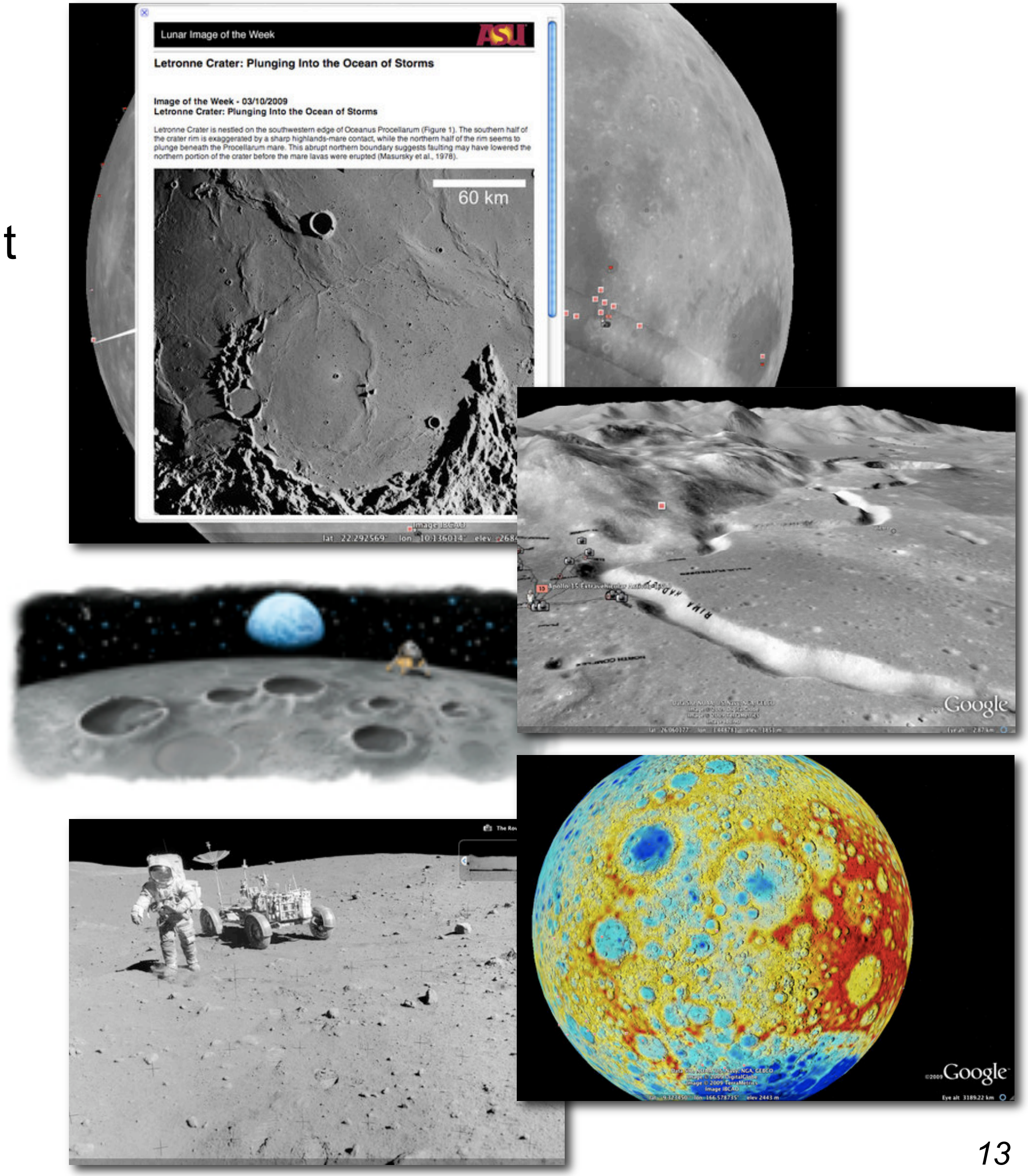
Moon in Google Earth

Explore the Moon in 3D

- Released July 20, 2009
- Co-developed with Google
- NASA Ames created content & processing scripts

Content

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



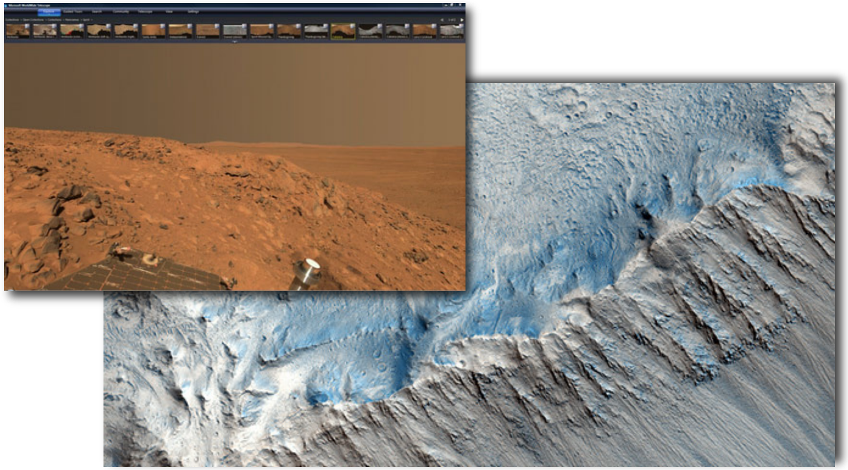
WorldWideTelescope | Mars

Complete HiRISE Mosaic

- Mars Reconaissance Orbiter HiRISE imager
- 74,000 images
- Each image: 20K x 50K pixels (> 1 GB / image)

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



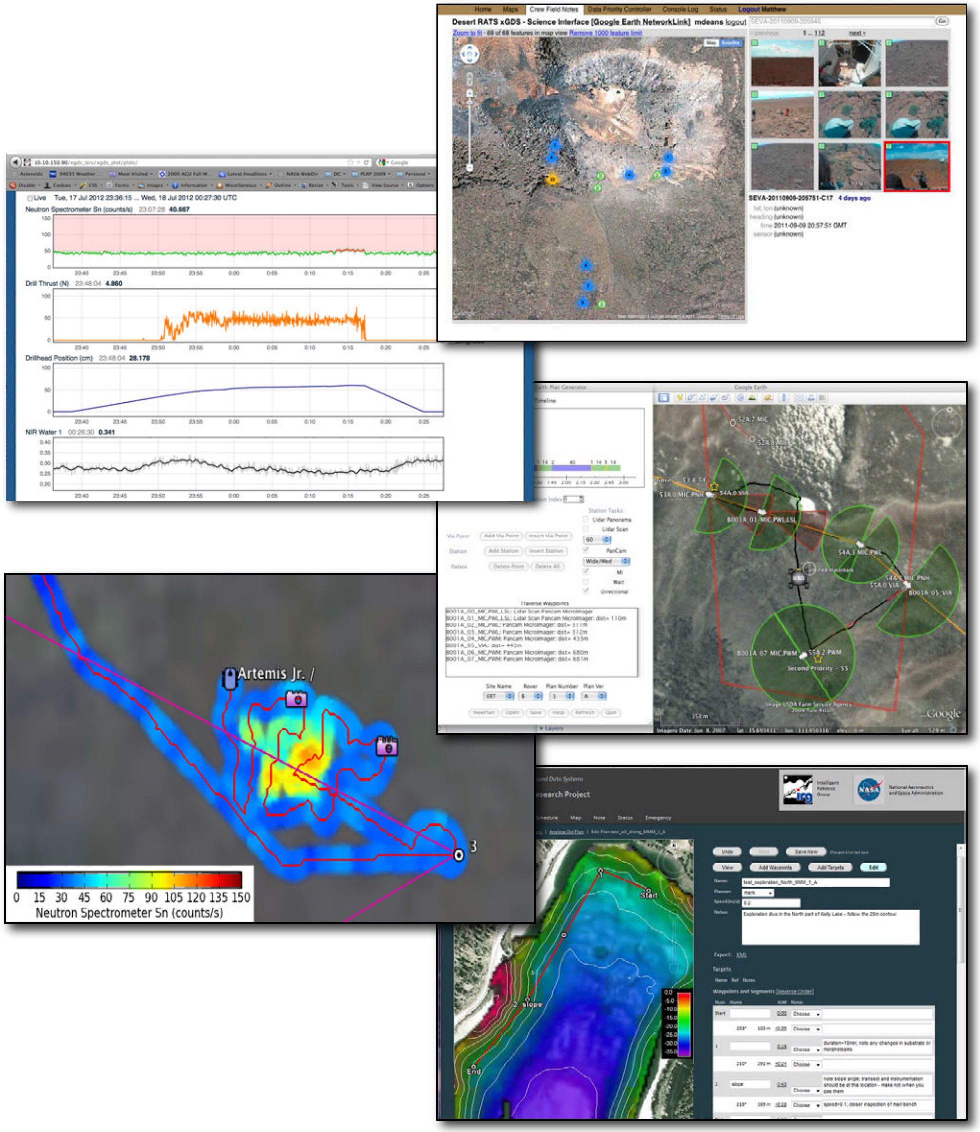
Exploration Ground Data System (xGDS)

xGDS is …

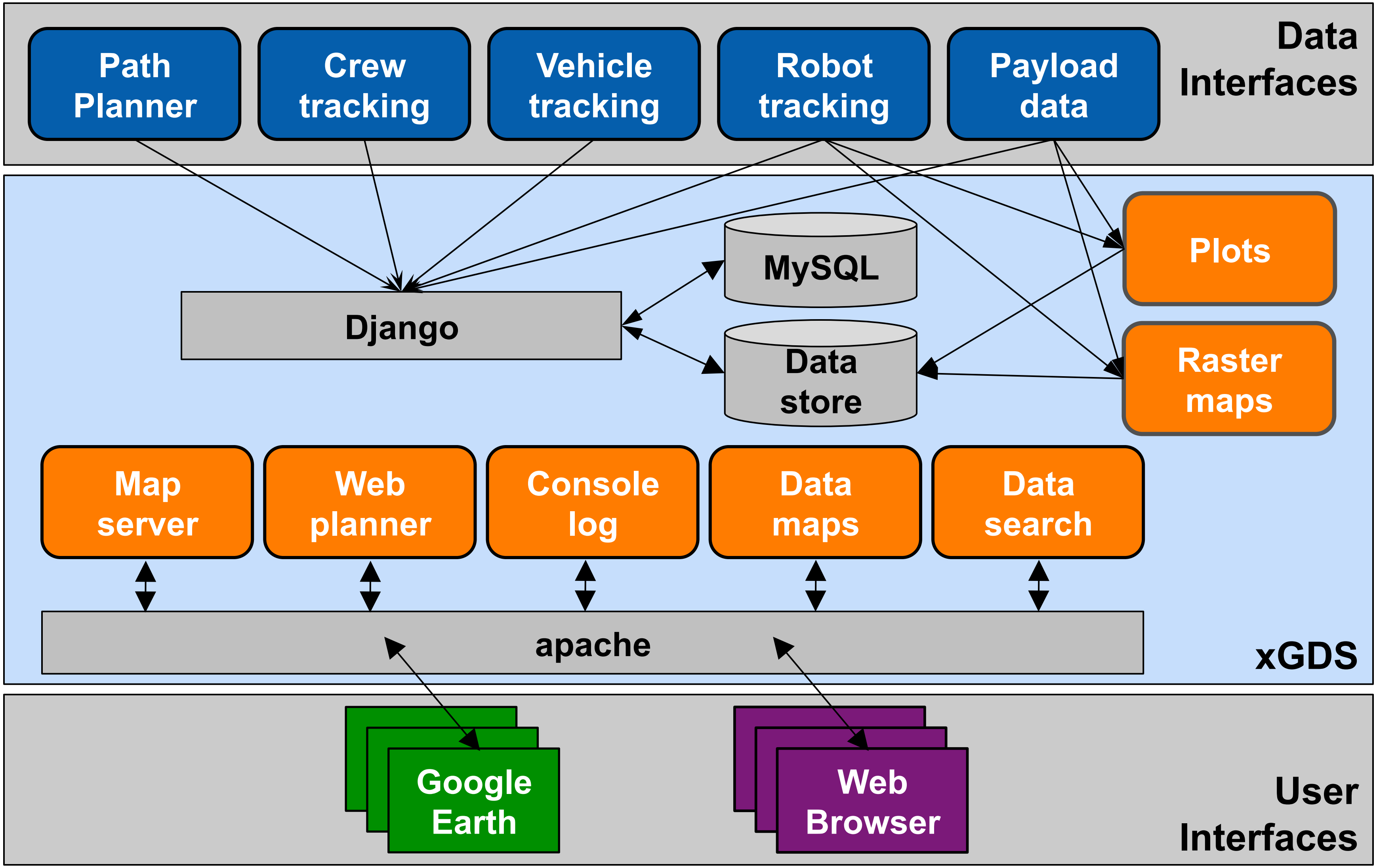
- Map content management
- Planning tool
- Real-time plots, maps, notes
- Post-processing data archive
- Browse and search tools

Users

- Field scientists
- Planetary scientists
- Mission planners
- Flight controllers
- Local & distributed teams

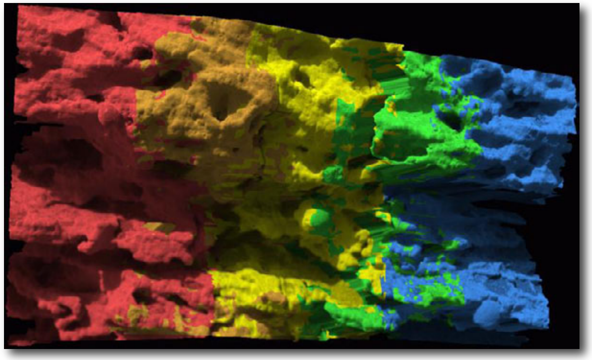


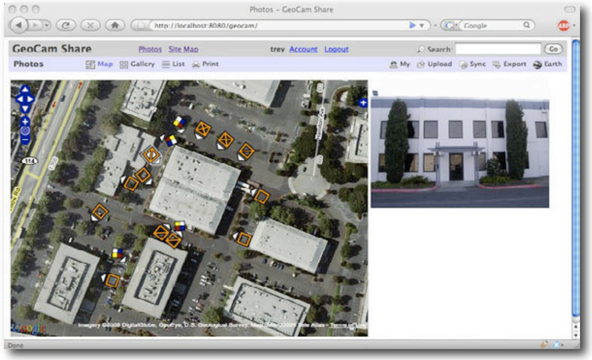
xGDS Architecture



IRG Open Source Software

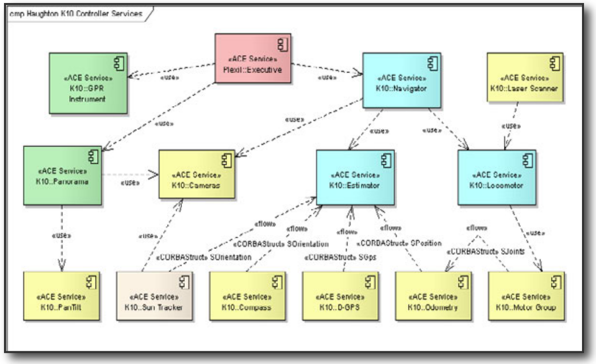
Vision Workbench

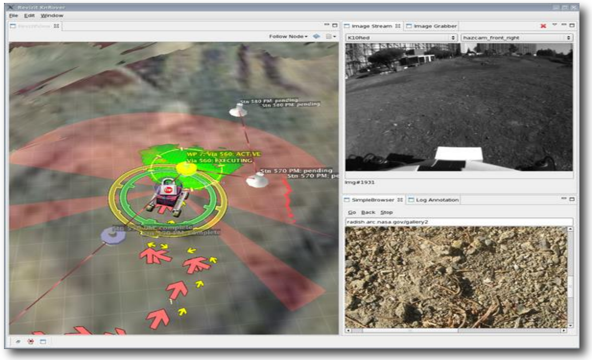




Exploration Ground Data Systems (**xGDS**)

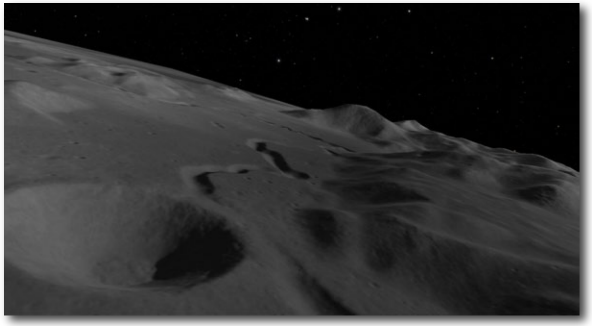
RoverSW

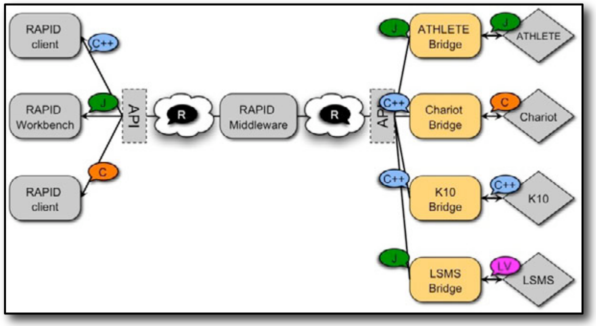




Visual Environment for Remote Virtual Exploration (**VERVE**)

Neo Geography Toolkit
(with Ames Stereo Pipeline





RAPID
(NASA robot middleware)

Questions?

Intelligent Robotics Group
Intelligent Systems Division
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irg.arc.nasa.gov

NASA Ames Planetary Mapping

Making NASA's data more rapidly and universally available

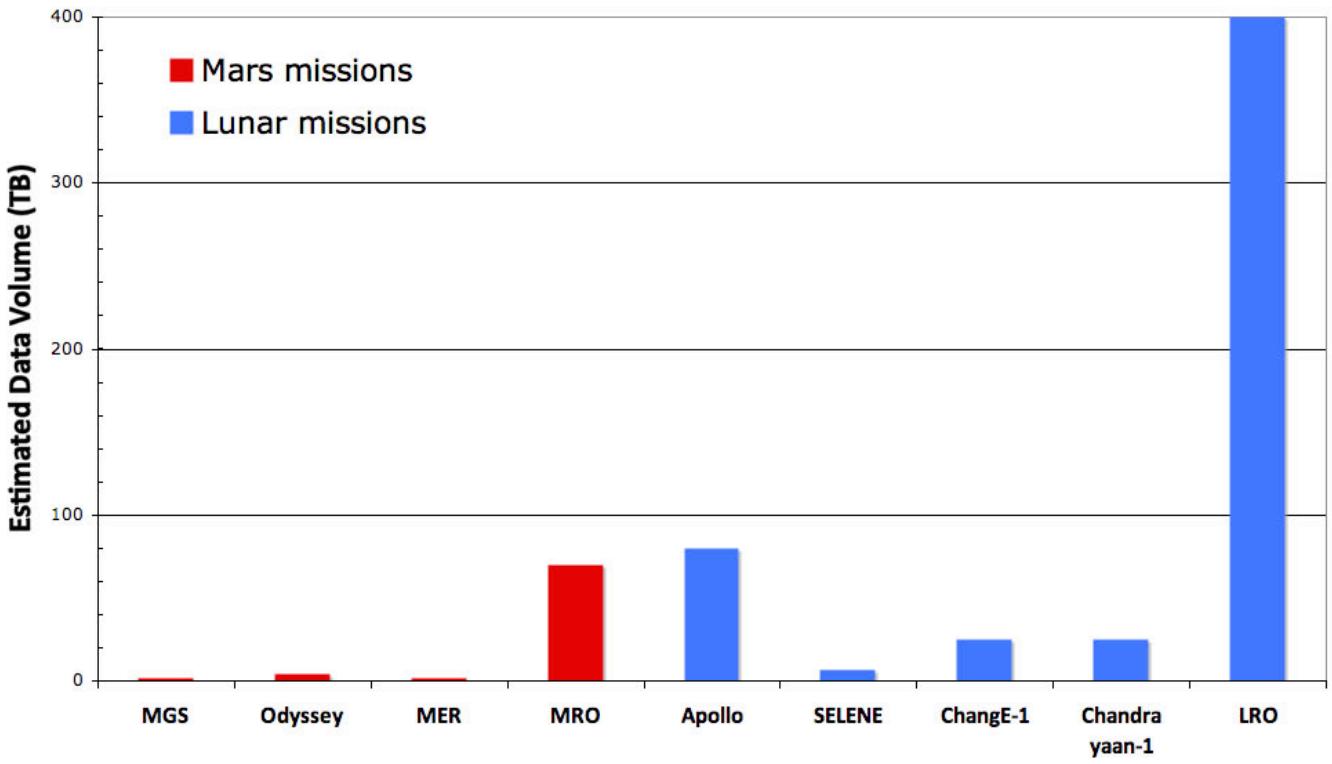
http://irg.arc.nas.gov
Intelligent Robotics Group
NASA Ames Research Center

Contact: terry.fong@nasa.gov

Really Big Data

Why do we need to build automated systems to handle large volumes of Planetary data?

We are in the midst of a major geospatial information explosion. For the first time, 10's of Terabytes of map data are being collected by robotic explorers.



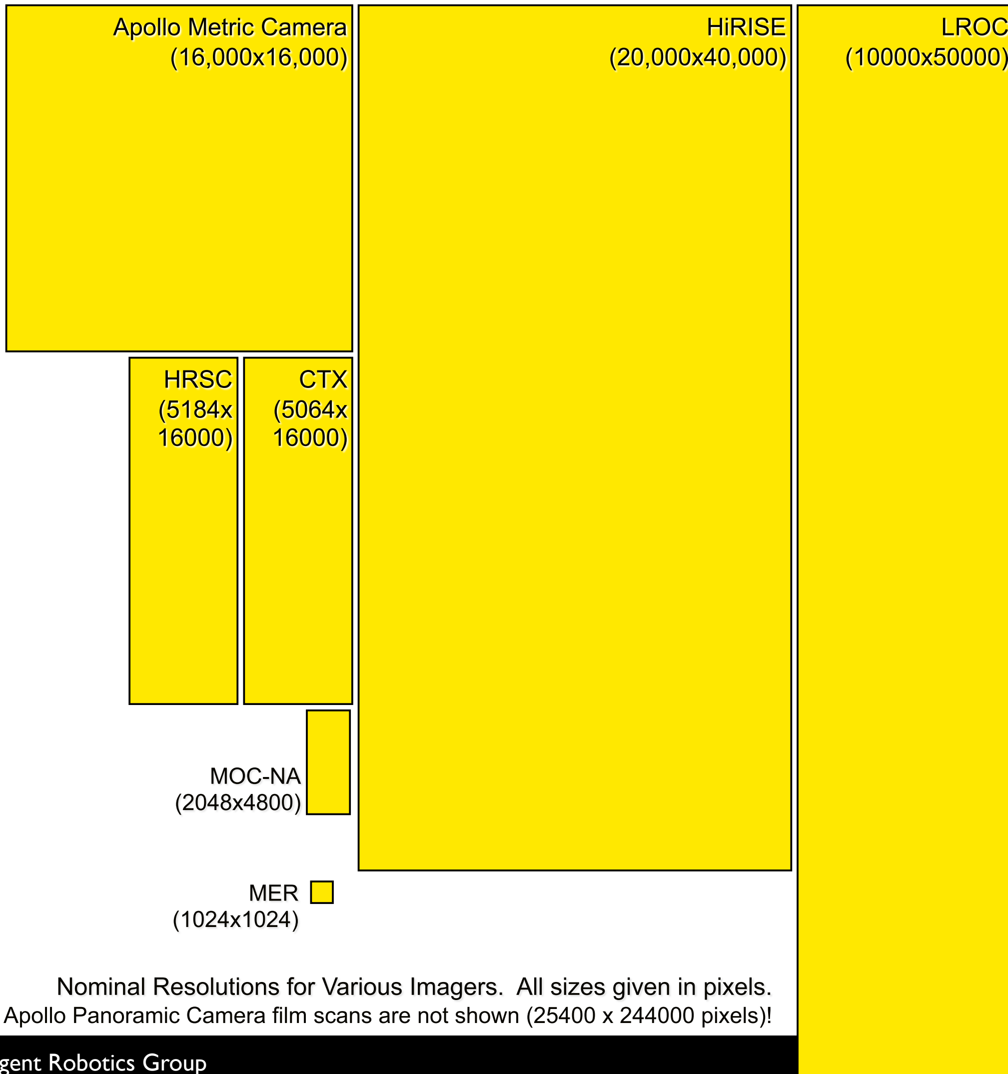
Approximate data volumes from various Mars (red) and Lunar (blue) missions.

Data volumes are in Terabytes!

Source: B. A. Archinal, L. R. Gaddis, R. L. Kirk, T. M. Hare, and M. R. Rosiek. Urgent Processing and Geodetic Control of Lunar Data. Workshop on Science Associated with the Lunar Exploration Architecture, 2007.

Really Big Images

Why do we need to build automated systems to handle large volumes of Planetary data?



Nominal Resolutions for Various Imagers. All sizes given in pixels.
Apollo Panoramic Camera film scans are not shown (25400 x 244000 pixels)!

- In the past, widely used maps such as the Viking MDIM mosaic took years to produce.

- Today, human intensive processes can be automated so that data can be processed & distributed more rapidly.

Some of our Projects

Automated 3D surface reconstruction, mosaicking, gigapixel imaging

- Bridging the gap between PDS and Geo-browser platforms

Enabling faster, easier, and universal access

- Developers in the Lunar Mapping and Modeling Program (LMMP)

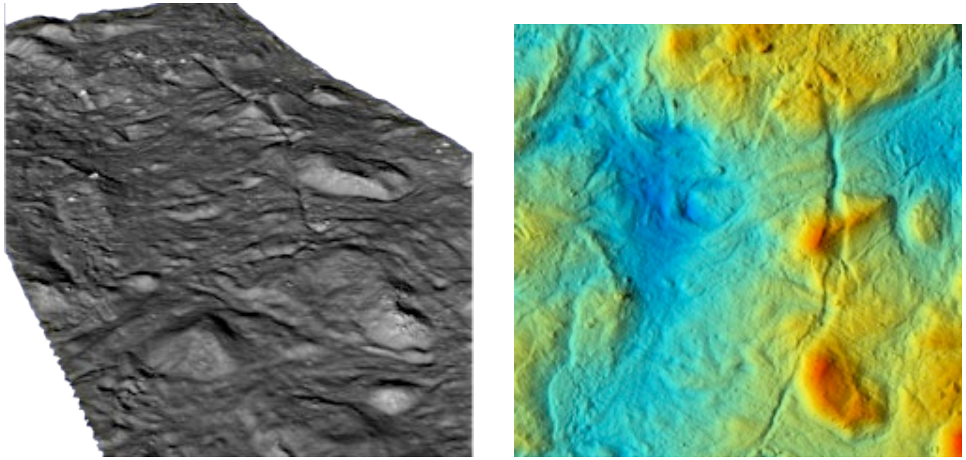
Providing stereo-derived topography and imagery from Apollo Metric Camera scans

- LROC & HiRISE Team Members

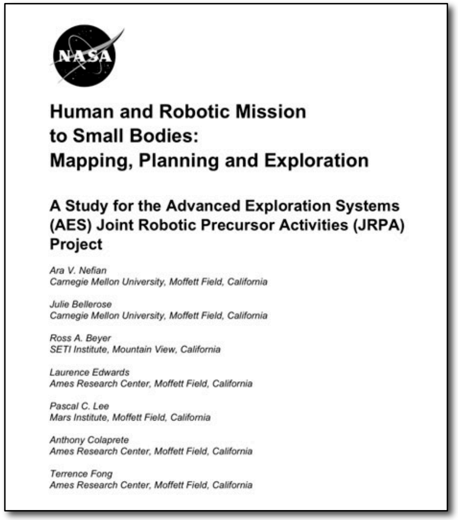
Validating and estimating the errors of LROC-derived DTMs

- Assorted other projects:

Vision Workbench, Ames Stereo Pipeline, Neo-Geography Toolkit, Small body mapping



Automated Stereo Reconstruction of Jackson Crater (LROC)



Human and Robotic Mission to Small Bodies: Mapping, Planning and Exploration

A Study for the Advanced Exploration Systems (AES) Joint Robotic Precursor Activities (JRPA) Project

Ara V. Nefian
Carnegie Mellon University, Moffett Field, California

Julie Bellerose
Carnegie Mellon University, Moffett Field, California

Ross A. Beyer
SETI Institute, Mountain View, California

Laurence Edwards
Ames Research Center, Moffett Field, California

Pascal C. Lee
Mars Institute, Moffett Field, California

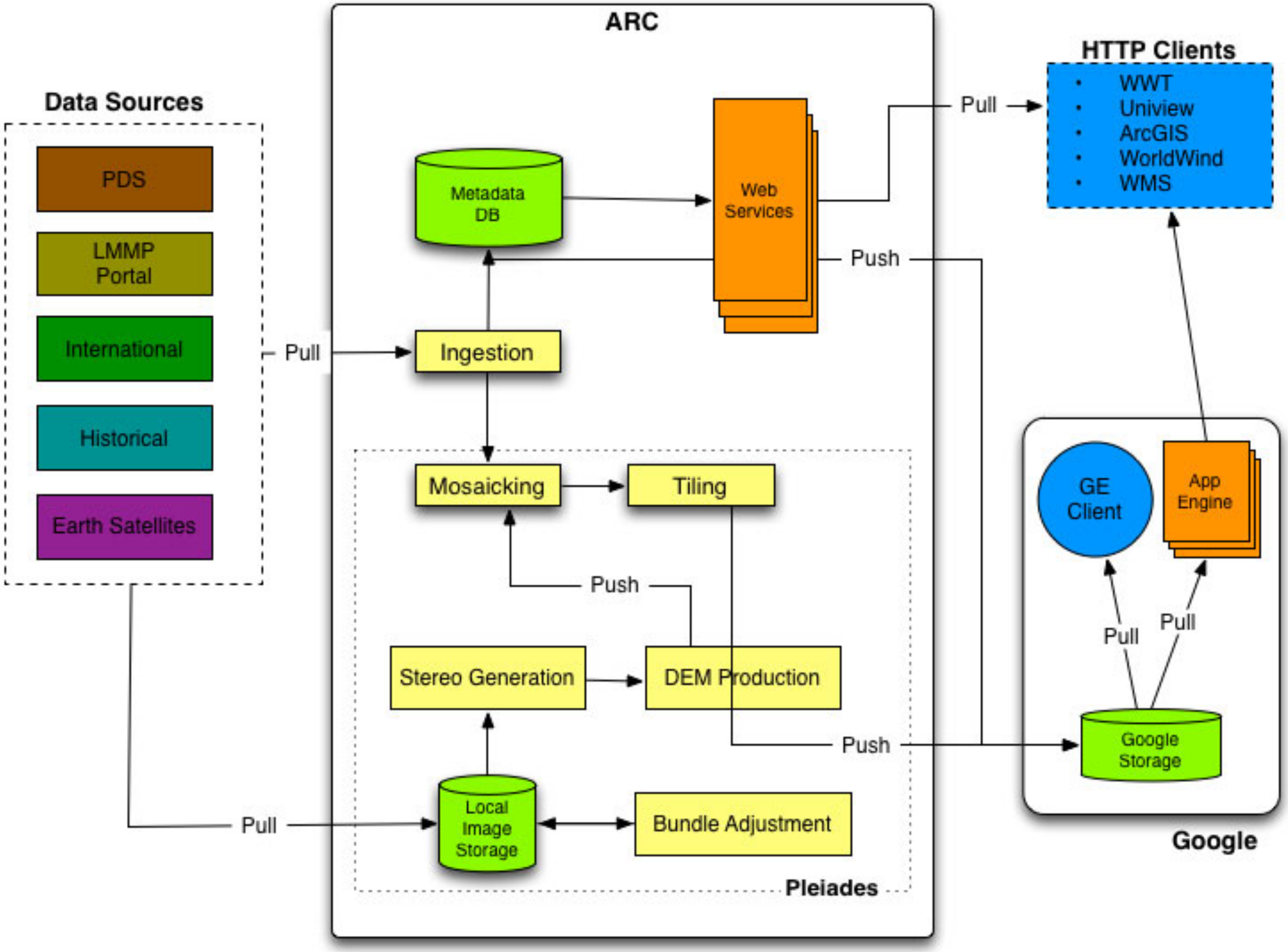
Anthony Colaprete
Ames Research Center, Moffett Field, California

Terrence Fong
Ames Research Center, Moffett Field, California

Our Automated Pipeline

Unified architecture for processing & serving planetary data through web services

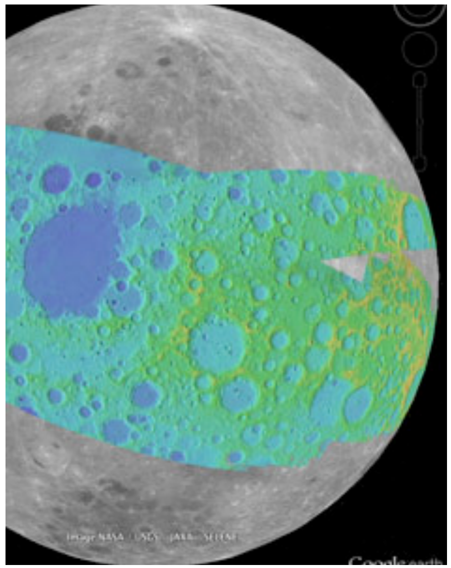
- Our geospatial data pipeline has been developed to automatically produce high-quality planetary maps and models
- It is extremely flexible & extensible, supporting many data source and open standards & protocols.
- Our software stack runs on Pleiades, the NASA Ames supercomputer



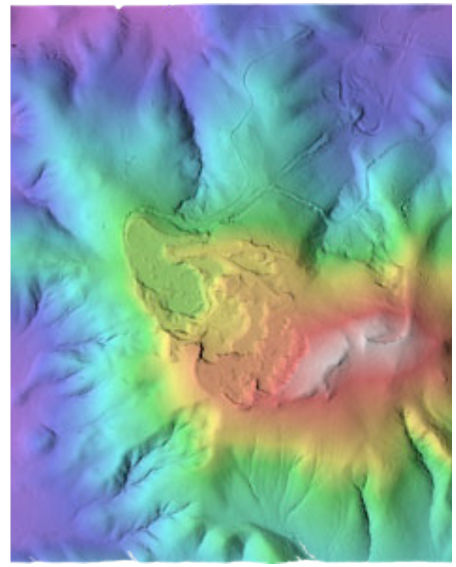
Ames Stereo Pipeline

Open-source automated stereogrammetry software

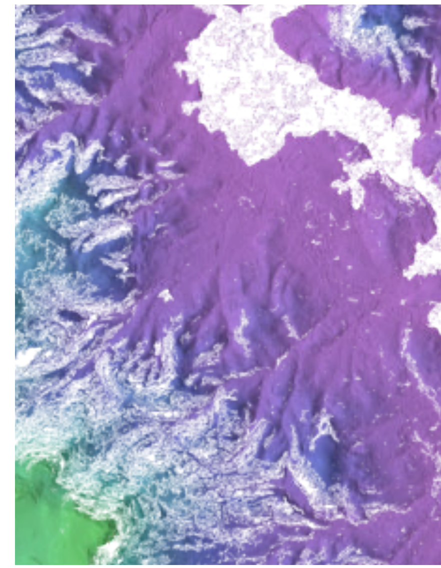
Models from traditional stereo cameras using the **TSAI** format.



Models of the other planets using USGS's **ISIS** cube files.



Models of Earth using **Digital Globe** Stereo 1B imagery.

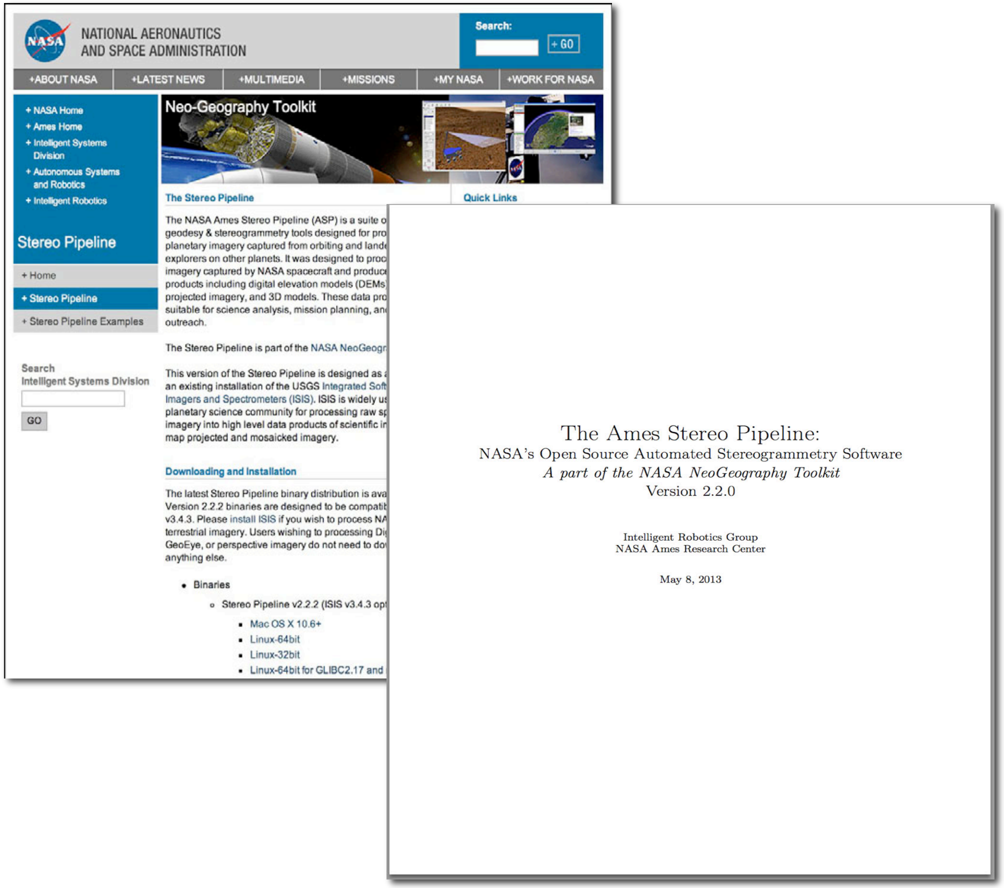


Models of Earth using imagery that contains an **RPC** Model.

Ames Stereo Pipeline (ASP)

Open-source automated stereogrammetry software

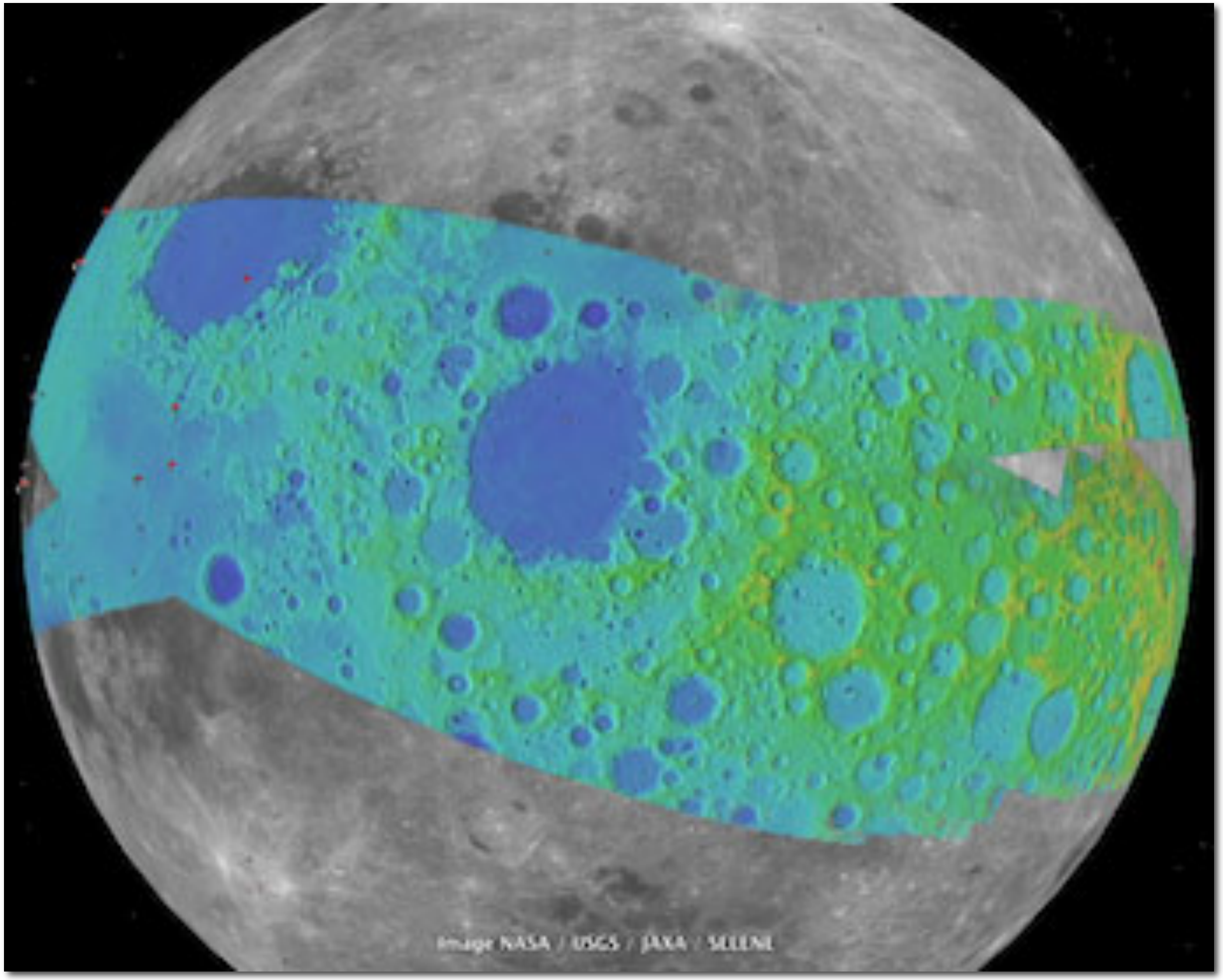
- What it is…
  - Command-line tools for computing clusters and super computers
  - C++ code hosted on GitHub
  - Binaries available for Linux and OS-X
  - Apache 2 license
- Data processed with ASP
  - Apollo Metric Camera
  - Digital Globe 1B products
  - Lunar Reconnaissance Orbital Camera (LROC-NA)
  - Mars High Resolution Imaging Science Experiment (HiRISE)
  - Mars Orbiter Camera (MOC)
  - MRO Context Camera (CTX)



tiny.cc/ames-stereo-pipeline

Apollo Zone DEM

High-resolution terrain model (digital elevation map)

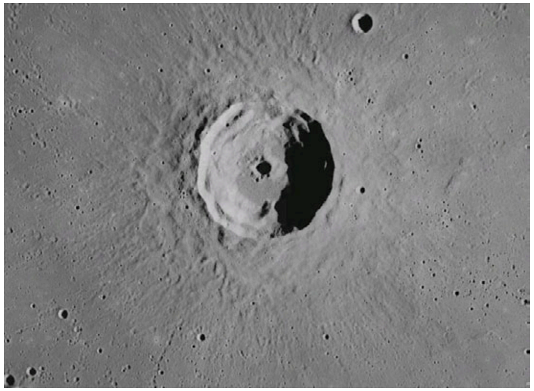


- Mosaick of 4,000 images
  - Apollo Metric Camera
  - 73,728 x 368,640 pixels
- Equatorial Lunar Surface (38S-34N lat)
  - 1,024 pixel / deg
  - Vert. acc 40.9m (LOLA)
  - Vert. stdv 37.8m
  - Horiz. acc 91.3m (LOLA)
- Controlled to LOLA through LRO-WAC
- 40,000 CPU hours (4 days on NASA Pleiades)

Albedo Reconstruction

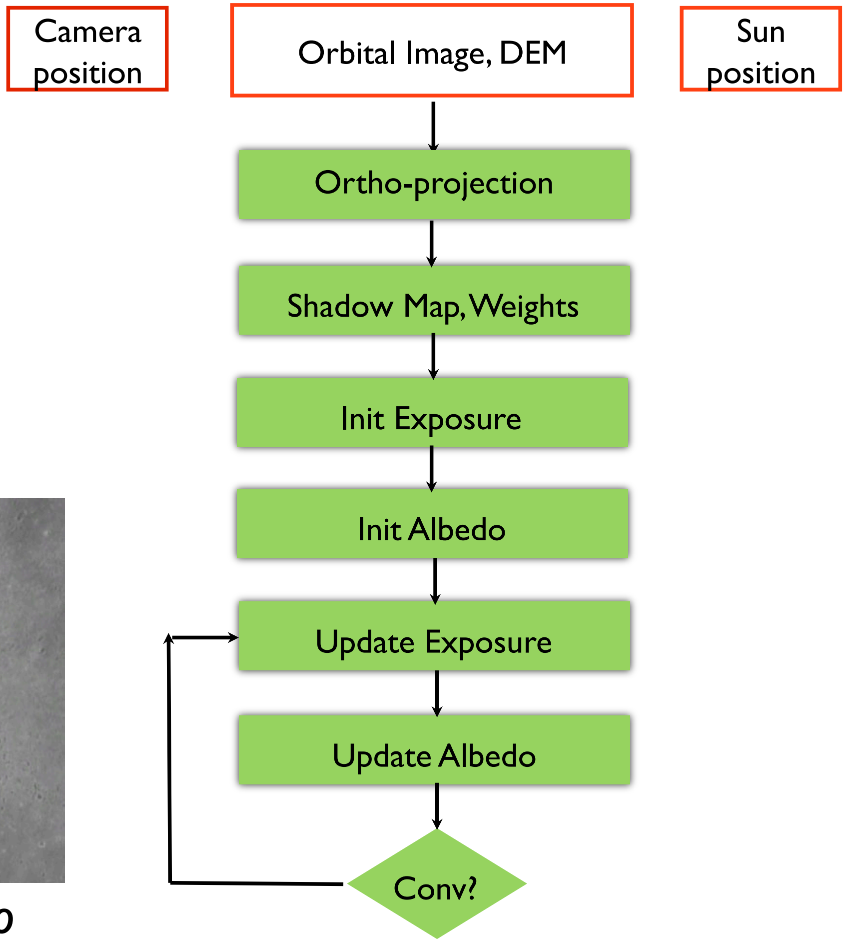
Scalability from single core to super computer (GNU parallel)

- **Image formation model:** Camera Transfer Function, Albedo, Exposure Estimation, Surface Reflectance, and Shadow
- For the Moon, uses Lunar-Lambertian Model (can be extended to non-Lunar surfaces) to reduce the effect of varying illumination
- Overlapping images allows for shadow removal



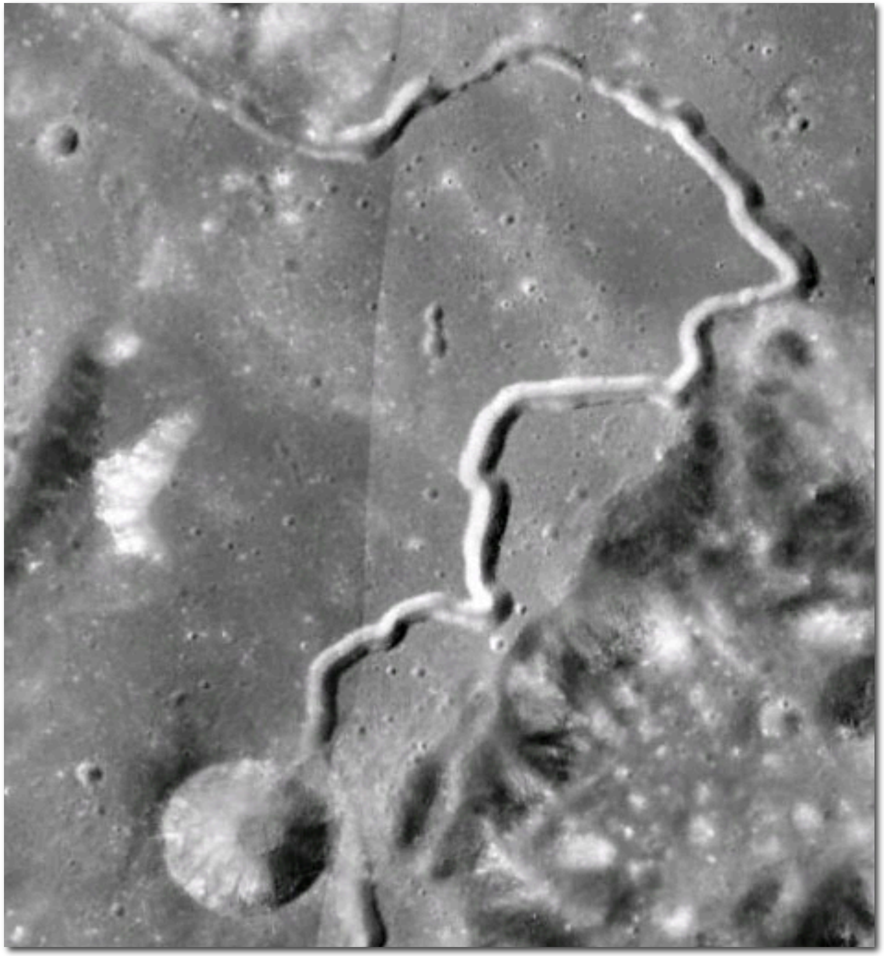
Original

Reconstructed albedo



Albedo Reconstruction

Hadley Rille (Apollo Metric Camera images)

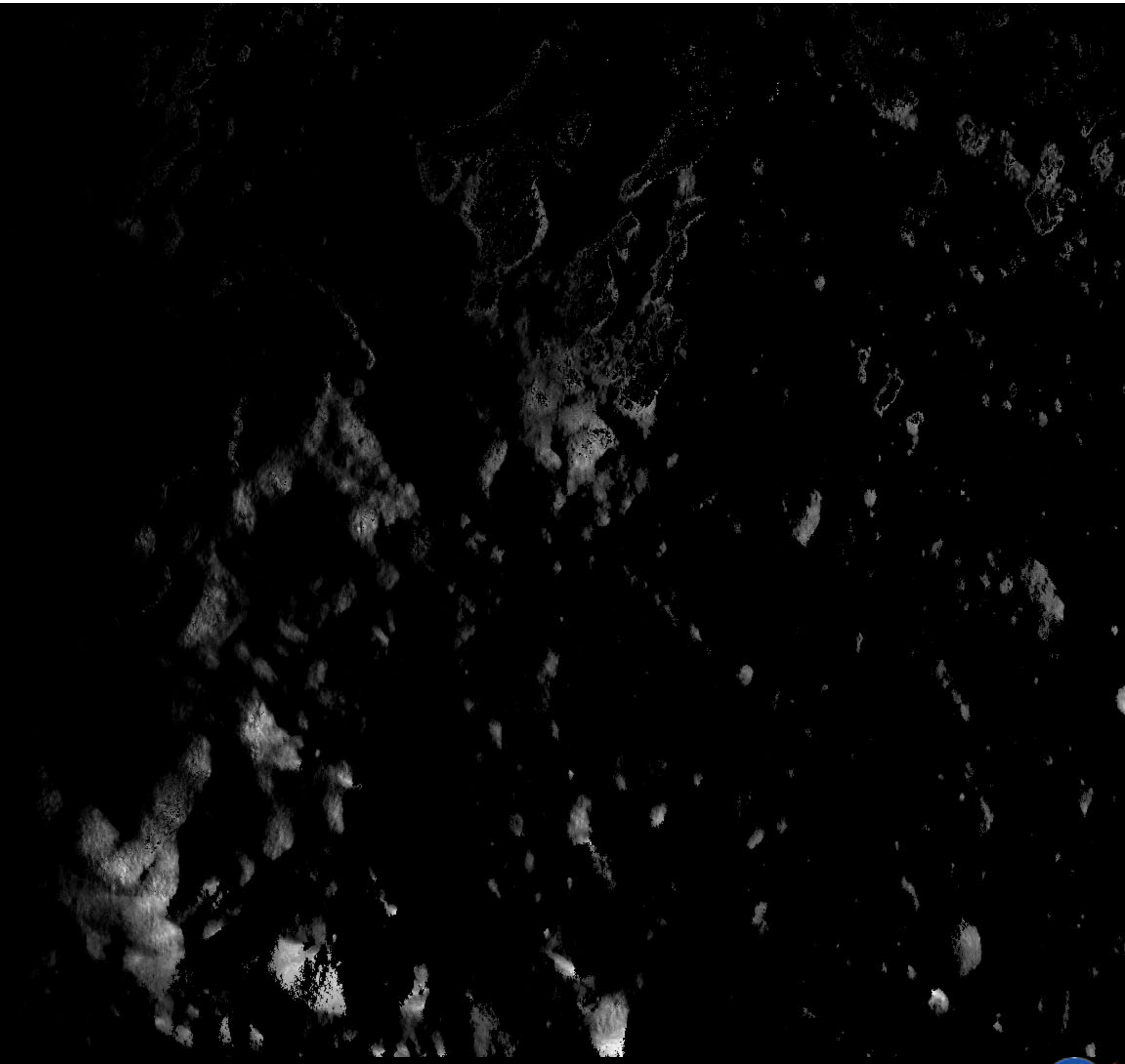


Original

Reconstructed albedo

Albedo Reconstruction

Hadley Rille (Apollo Metric Camera images)



Apollo Zone DIM

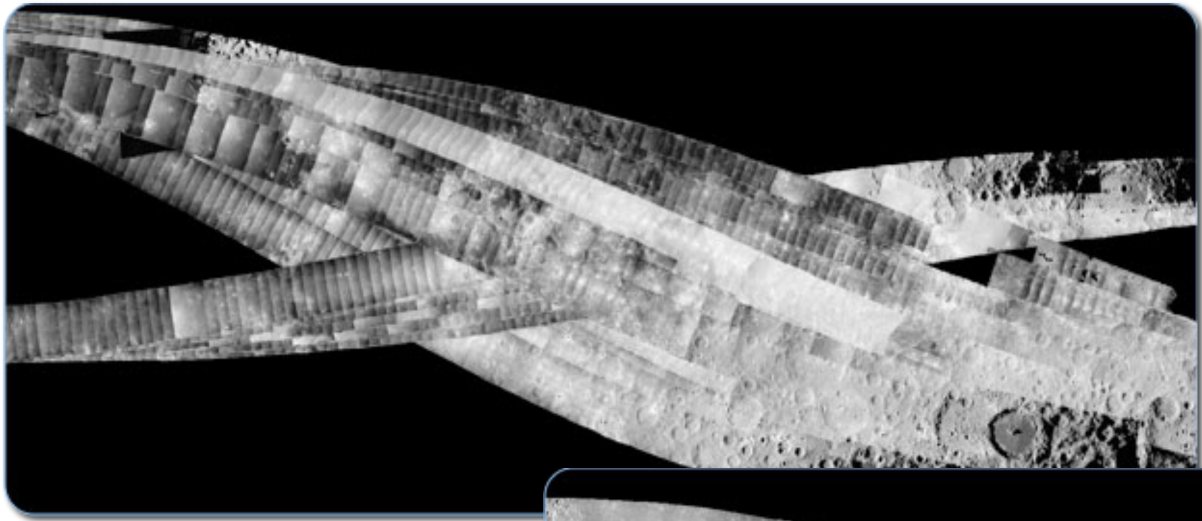
High-resolution base map (digital image mosaick)

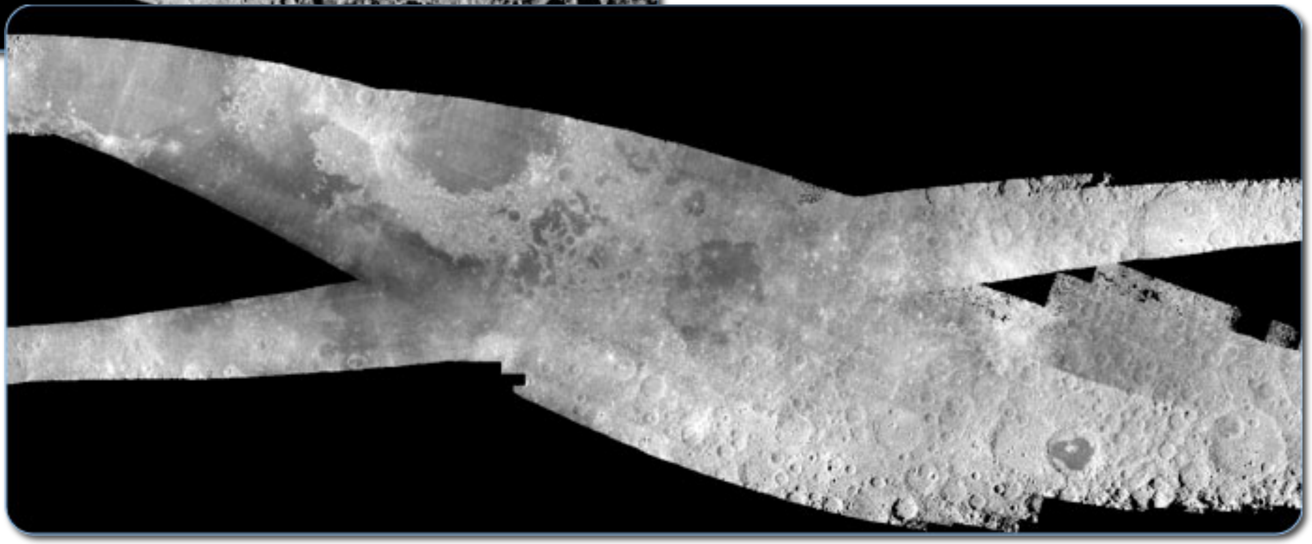
Albedo Maps

Data	Resolution	Coverage
LRO-WAC	100 m/pixel	100%
LRO-NAC	1 m/pixel	< 2% (early 2013)
Apollo Metric	10 m/pixel	18%

Mosaicking & Blending

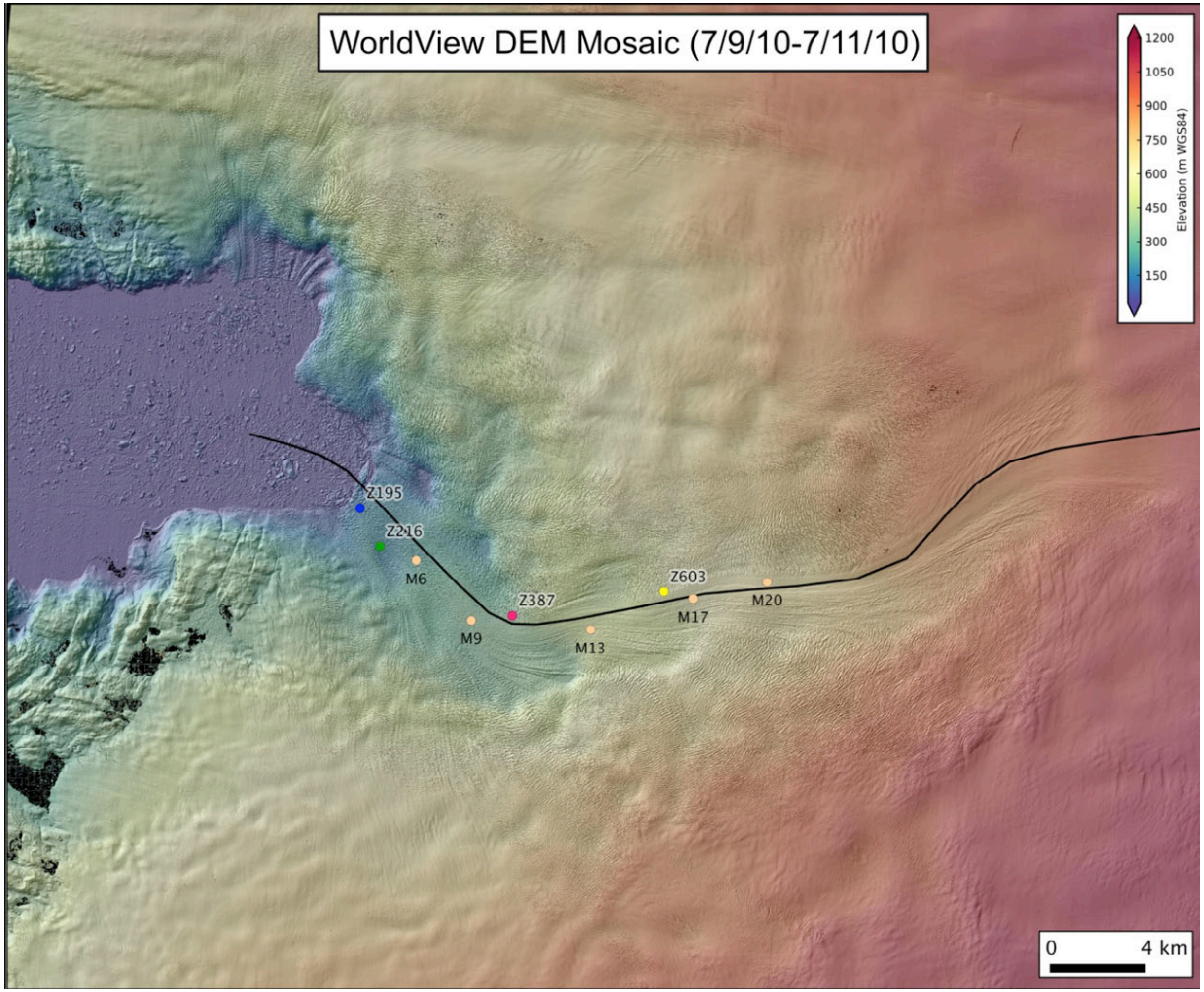
Highly accurate reconstruction, blending, and error modeling





ASP for Earth

Cryospheric mapping for Earth science (glaciology, climate change, etc)

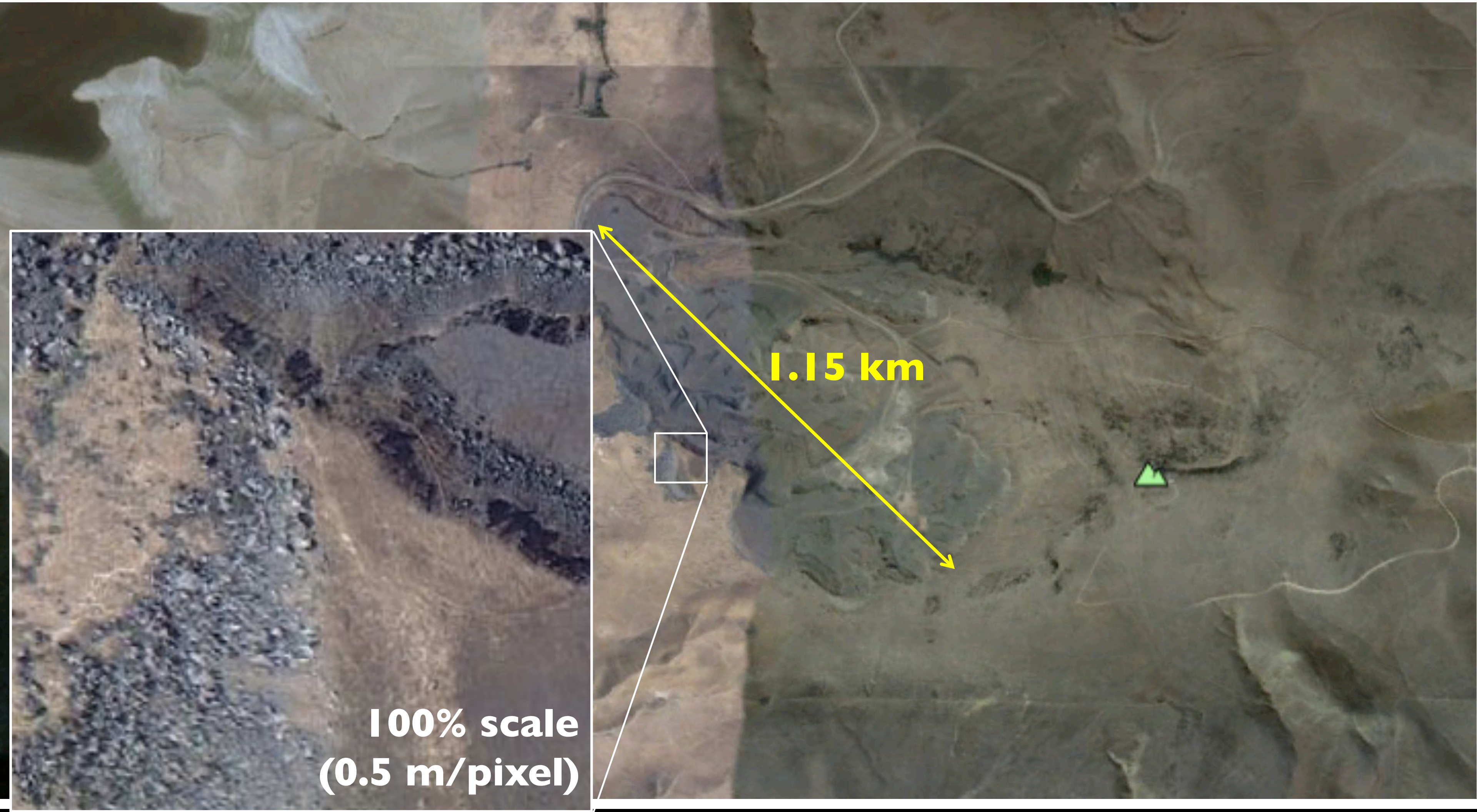


Jakobshavn Glacier, Greenland

- 6 input images
- 2500 km^2 coverage
- 5 m/post

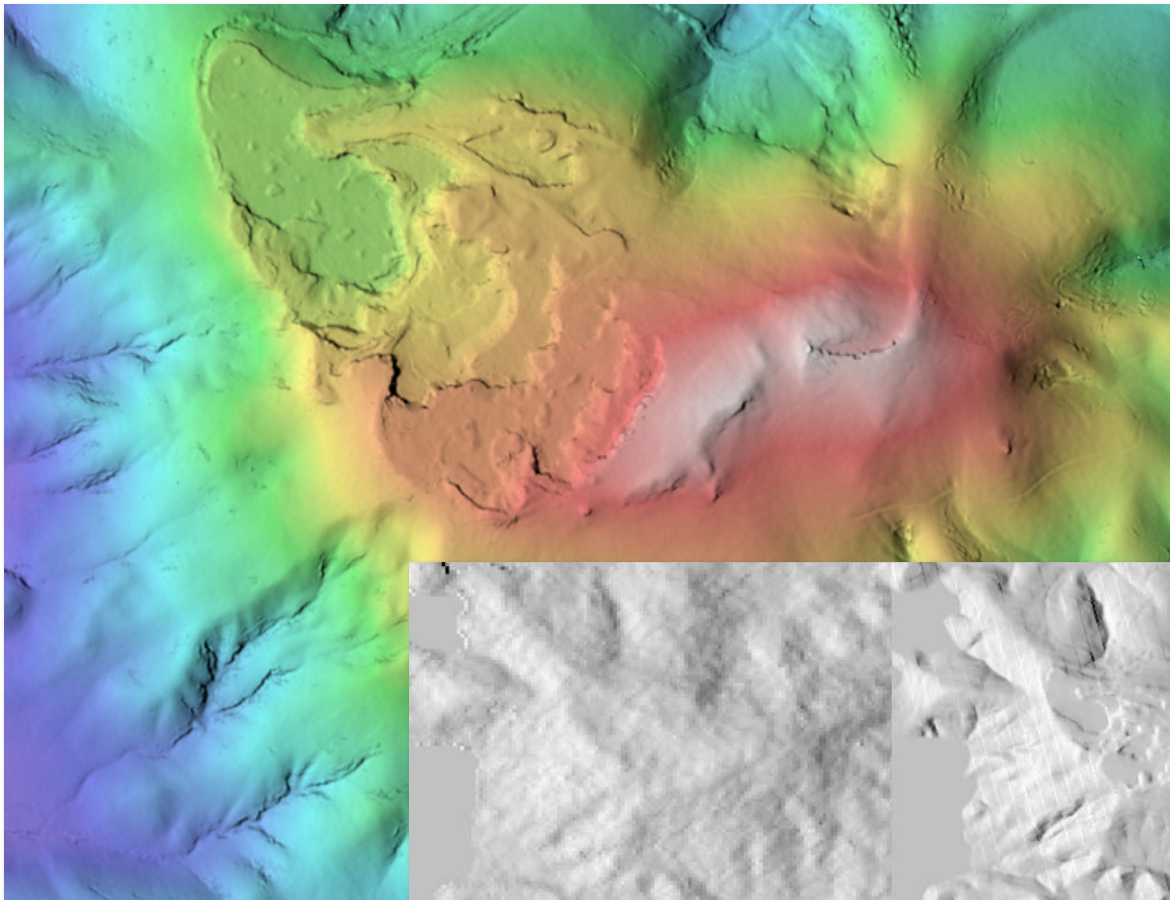
ASP for Earth

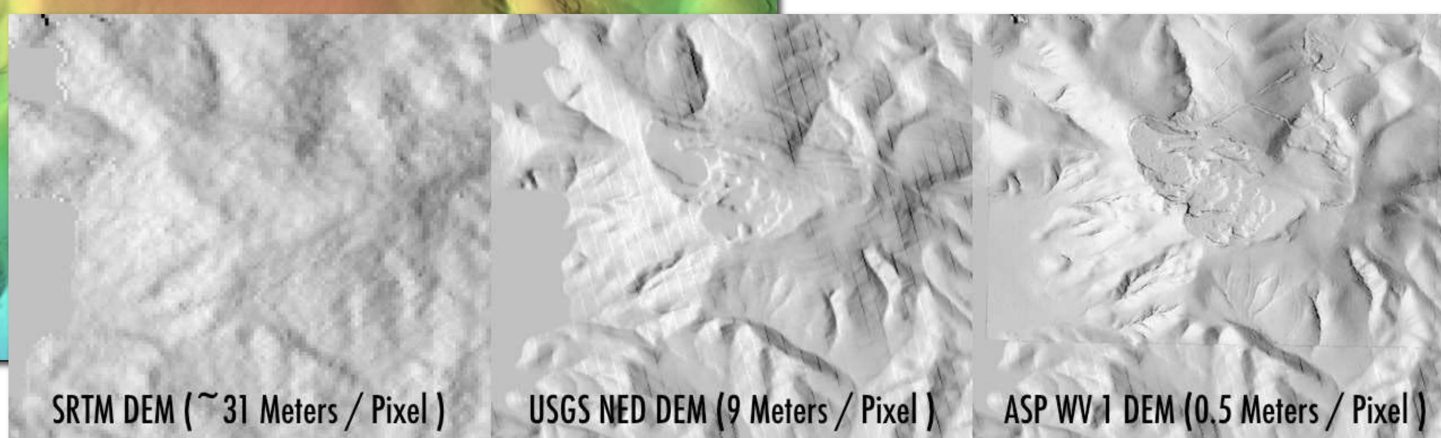
Non-vegetated areas



ASP for Earth

60% success rate processing Digital Globe stereo pairs without human input

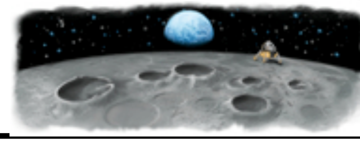




- Colorized DEM of the Basalt Hills Quarry
- Used for planetary rover analog testing
- Based on DigitalGlobe WorldView imagery

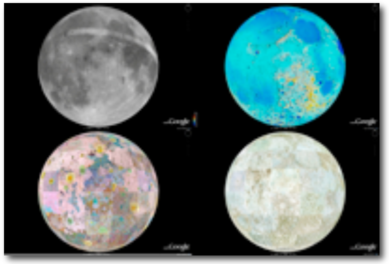
NASA / Google

Explore the Moon and Mars in 3D

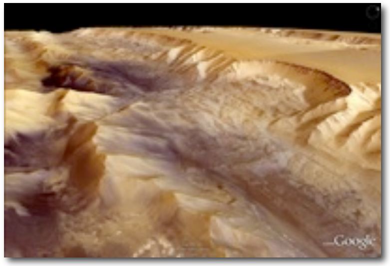


- "Google Moon" & "Google Mars" provide data availability & fusion for planetary data
- Includes "live" imagery of Mars from the THEMIS camera (appears on-line 2-4 days after downlink)
- Guided tours of the Moon and Mars narrated by Buzz Aldrin, Jack Schmitt, Ira Flatow, and Bill Nye.

Try it for yourself in Google Earth 5.0!

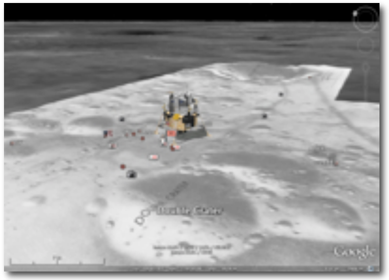


Modern / Historical Base Maps



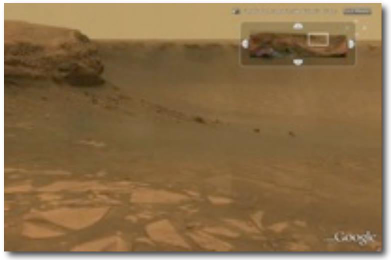
High Resolution 3D Terrain

Geospatial Image Browsing/Indexing



Tours Narrated by Notable Scientists and Astronauts

Geologic Maps



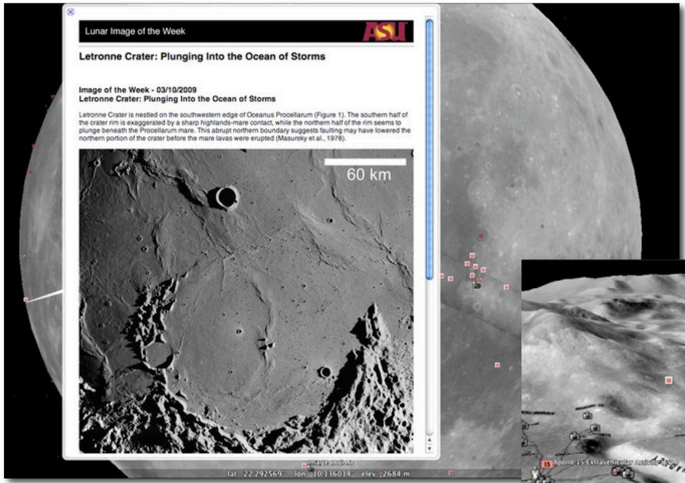
Geo-located Panoramic Imagery

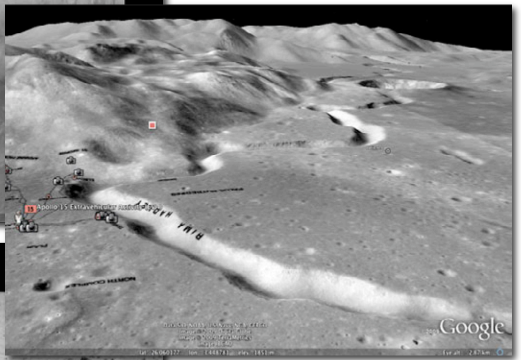
This work was done at ARC under a reimbursible space act agreement (RSAA).
The RSAA does *not* imply exclusive access to NASA data or to our team.

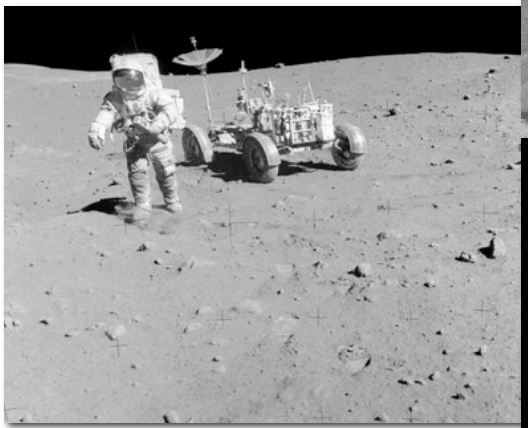
Google Moon

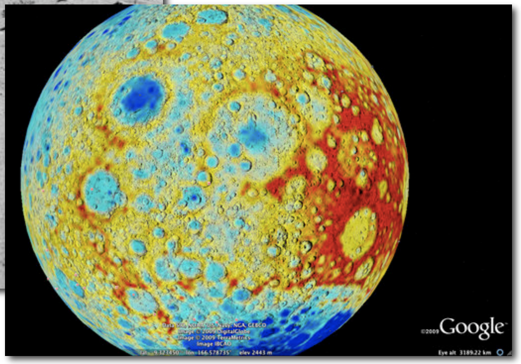
Released July 20, 2009

- "Moon for Google Earth"
  - Co-developed with Google
  - IRG created content, processing scripts, and base maps
  - Built in to Google Earth 5.0
- 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 and Jack Schmidt)
  - And much more …





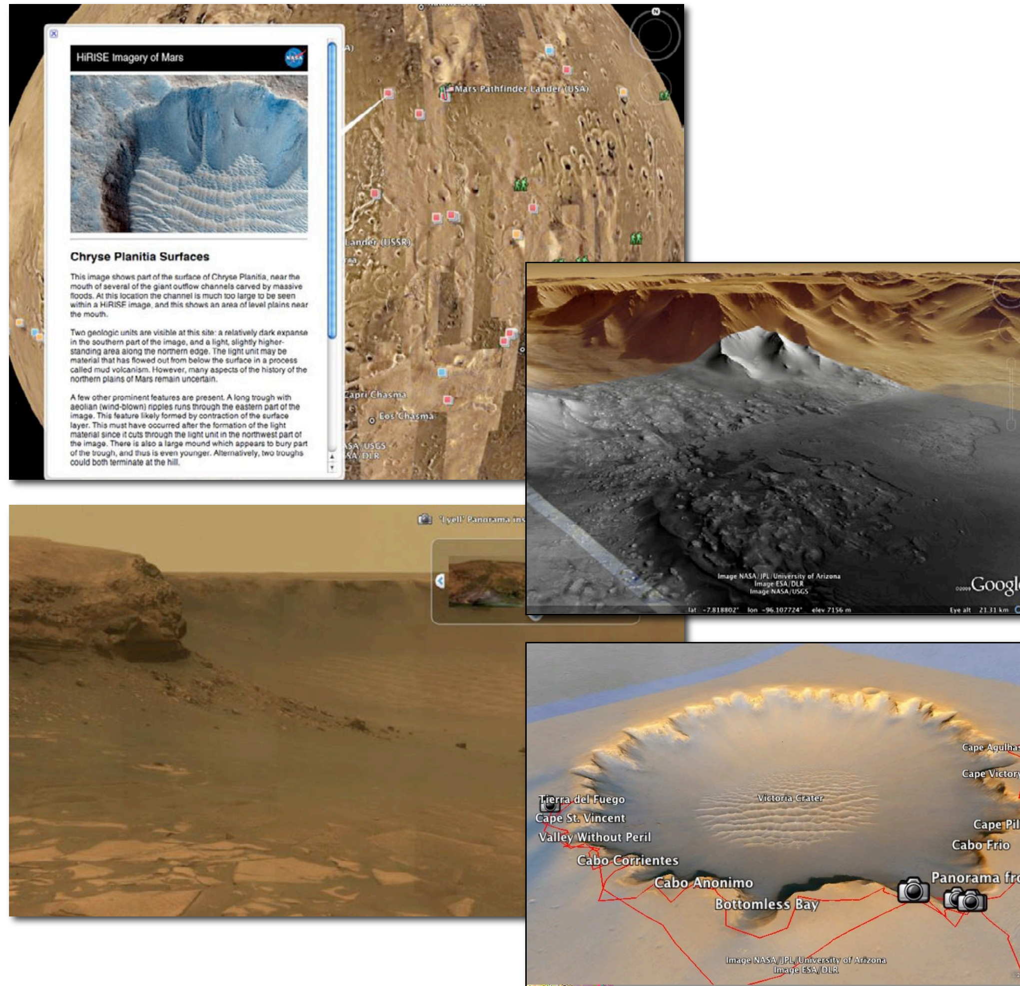




Google Mars

Released February 2, 2009

- "Mars for Google Earth"
  - Co-developed with Google
  - IRG created content, processing scripts, and base maps
  - Built in to Google Earth 5.0
- 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 …



NASA / Microsoft

Bringing the Mars experience to WorldWide Telescope

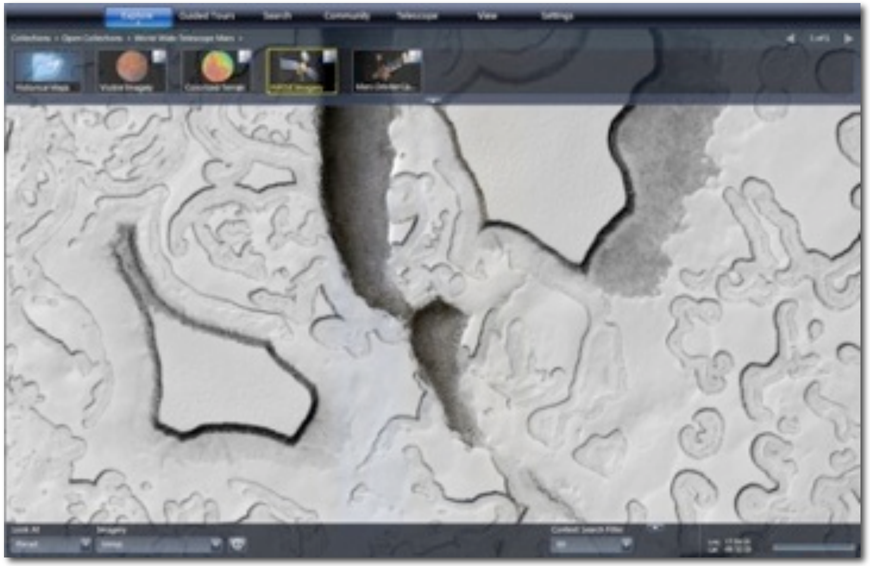
WWT | Mars

- Featuring the largest digital image mosaic of Mars ever created
- Data sets for WWT Mars were created using the NASA Nebula cloud computer

NEBULA Cloud Computing Platform alpha

- Guided tours of Mars narrated by Dr. Carol Stoker and Dr. Jim Garvin

http://worldwidetelescope.org



		MOC	HiRISE
INPUT	Total # of images	**74,359**	**13,342**
	Pixels / Image	16 Megapixels	1.25 Gigapixels
OUTPUT	Total Image Tiles	~38 Million	~526 Million
	Total Mosaic Size	**843 Gigabytes**	**12 Terabytes**

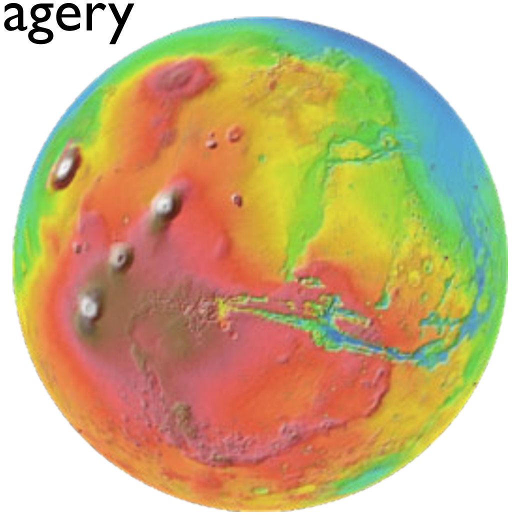
This work was done at ARC under a reimbursible space act agreement (RSAA).
The RSAA does *not* imply exclusive access to NASA data or to our team.

WWT Mars Base Layers

New global maps and historical imagery

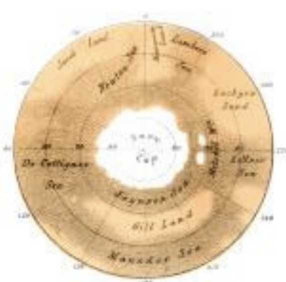
Global Imagery

Color MDIM v2 (merged w/ MOC-WAC mosaic)



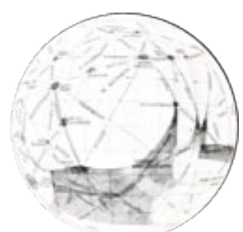
Mars Topography (MOLA)

Historical Imagery

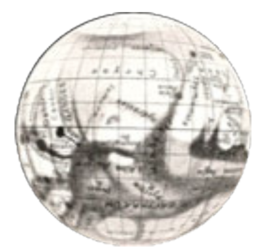


Nathaniel Green (1877)

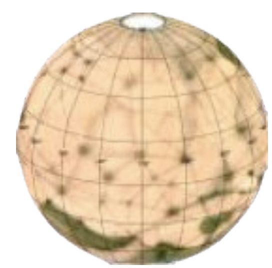
Giovanni Schiaparelli (1890)



Percival Lowell (1896)



Eugene Antoniadi (1909)

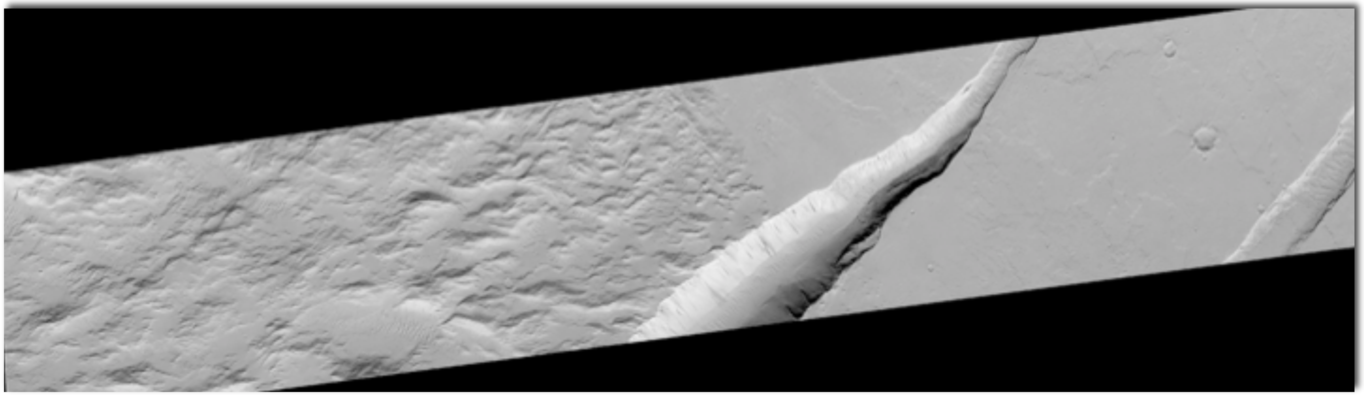


MEC-1 Prototype (USAF) (1962)

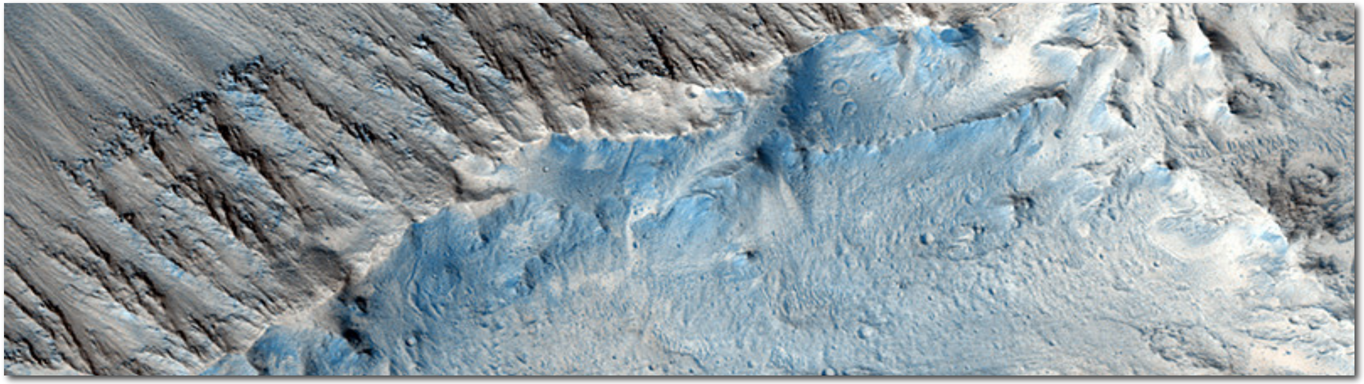
WWT High Resolution Layers

From Mars Global Surveyor and Mars Reconnaissance Orbiter

74,359 Mars Global Surveyor MOC Images



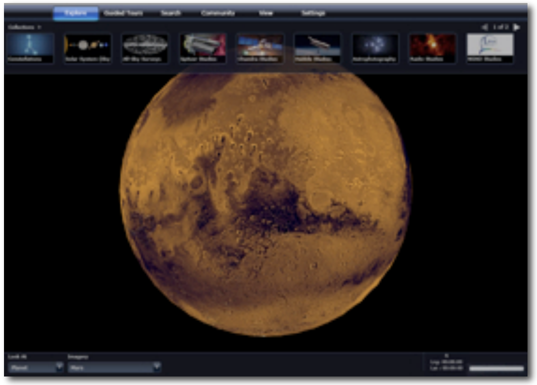
13,342 Mars Reconnaissance Orbiter HiRISE Observations



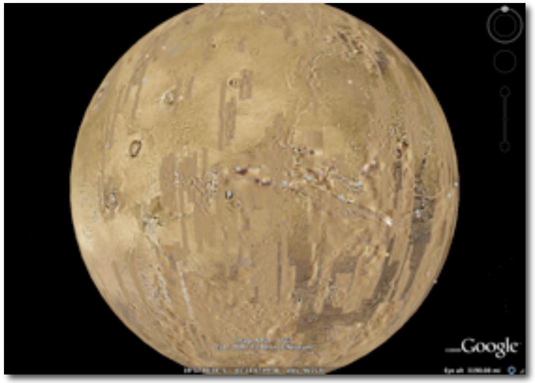
Access to Planetary Data

Providing 2D and 3D NASA imagery to cutting-edge geo-browser platforms

- NASA has done an exemplary job of archiving its data and making it publicly available (e.g. the PDS and DAACs), but these archives were not designed for immediate, on-demand access to the data.
- We believe that there is a need to bridge the gap between the PDS and users who are not "data experts."
- Ubiquitous, freely available geo-browser platforms are technologically well-suited to this task, and a natural fit to fill this gap.



Microsoft WorldWide Telescope (WWT)



"Google Moon" & "Google Mars" (in Google Earth 5.0)

Lunar Imagery for Uniview

Live Data into Google Earth

Continuous, automatic data release

Mission Instrument Team Provides

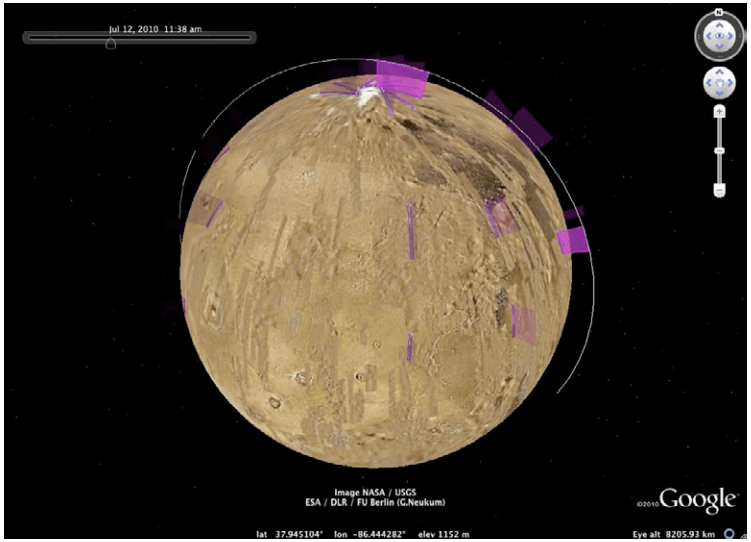
(via public or private URL)

Spacecraft Orbit
lon, lat, alt, time (CSV file)

Data Footprint
lat,lon of vertices (CSV file)

Instrument data
(ISIS cube, PNG, JPEG, etc.)

data pull
(periodic)



publish to
Google Earth

KML Convert

(using ARC Neo-Geography Toolkit)