Planetary Exploration *REINVENTED*

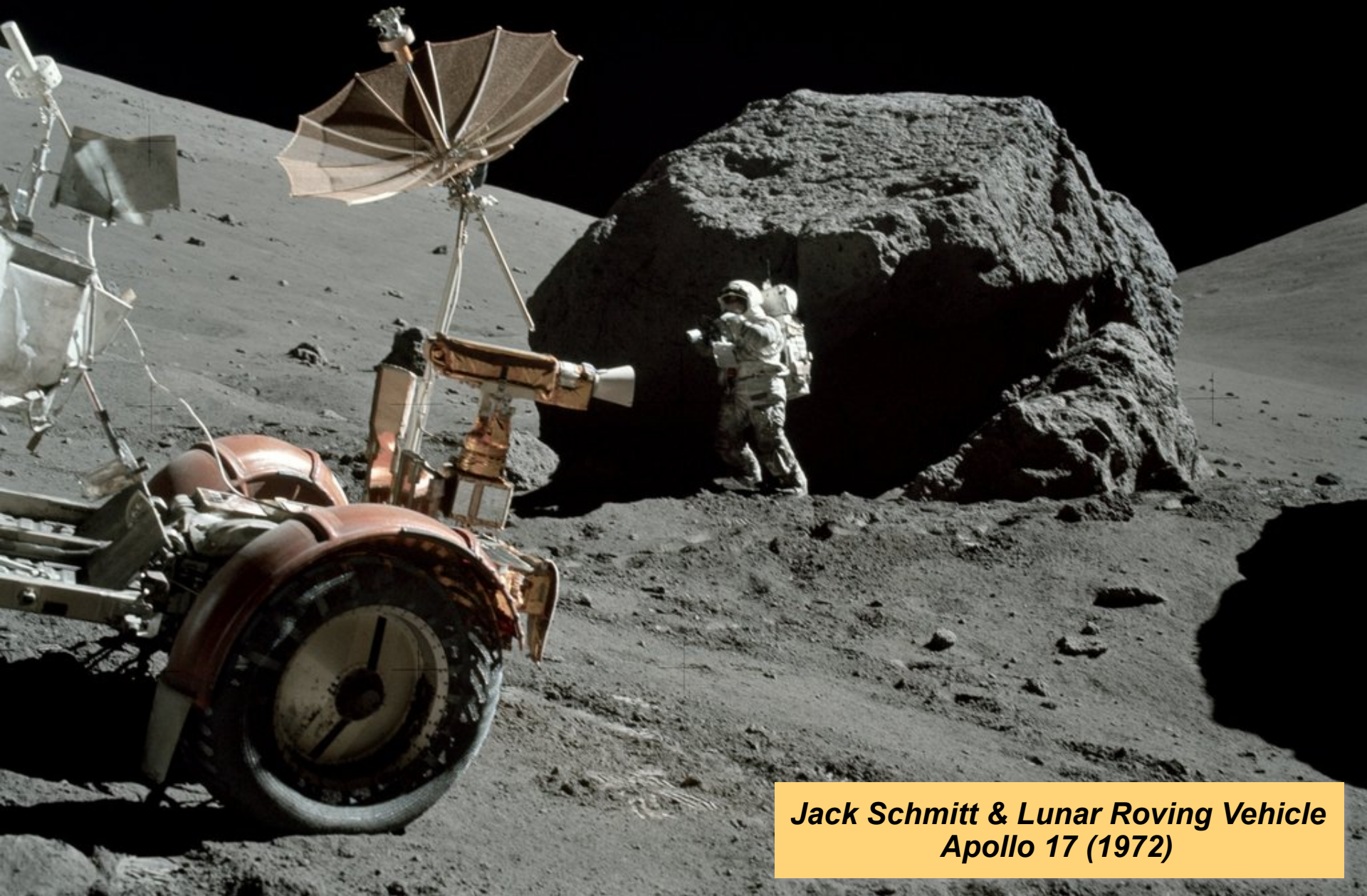
New ways of exploring the Moon, Mars, & beyond

Dr. Terry Fong

Intelligent Robotics Group
NASA Ames Research Center
terry.fong@nasa.gov

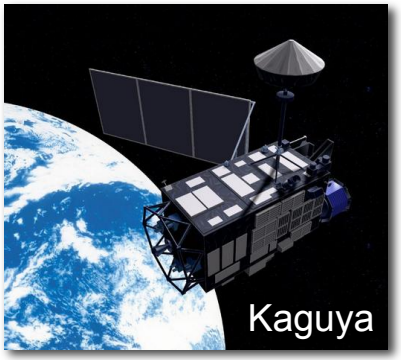
irg.arc.nasa.gov

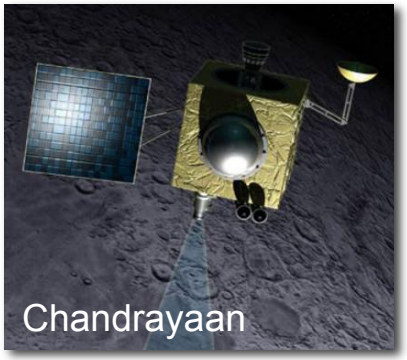
Human Planetary Exploration

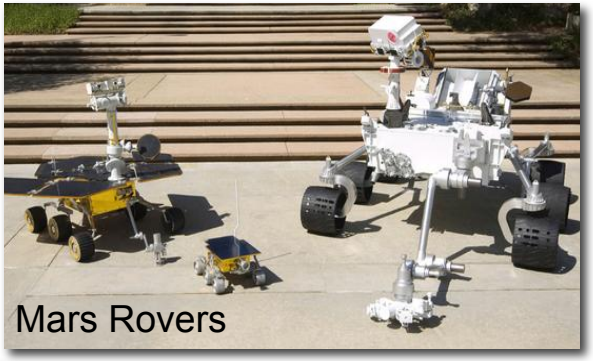


Jack Schmitt & Lunar Roving Vehicle
Apollo 17 (1972)

What's changed since Apollo?

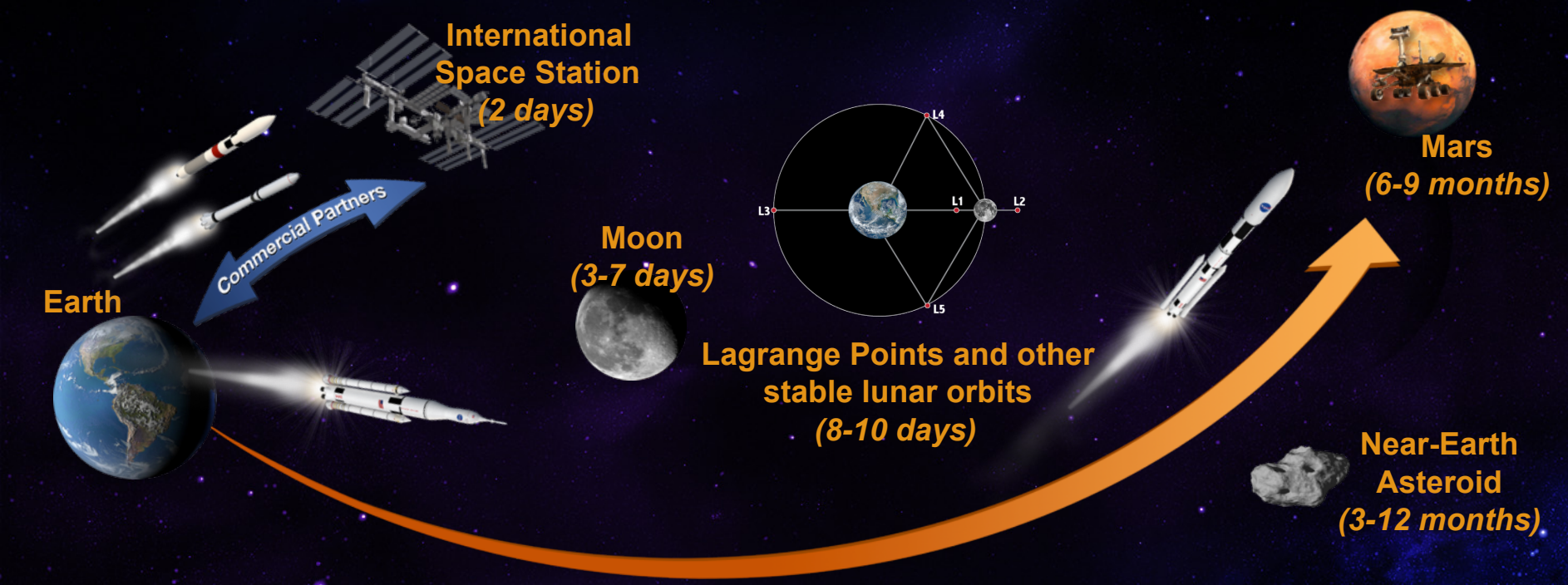




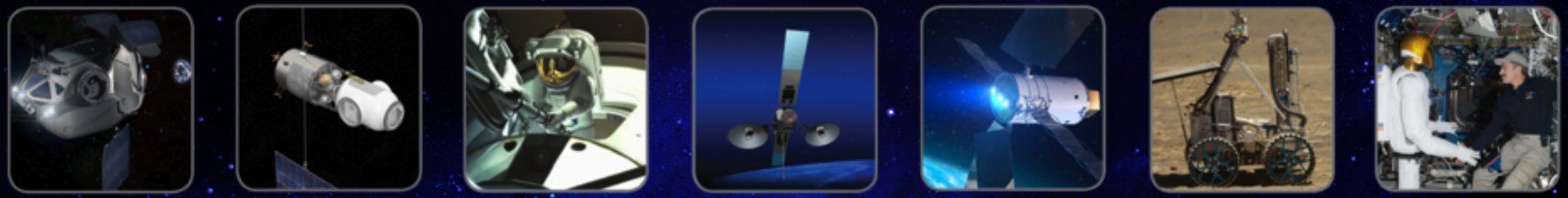


Exploration destinations

(one-way travel times)



Future missions will be longer, more complex, & require new technology



Robotics and Mobility | Deep Space Habitation | Advanced Spacesuits | Advanced Space Comm | Advanced Propulsion | Resource Utilization | Human-Robot Systems

New Ways of Exploring

Part 1: Robots for human exploration

- Complement & supplement humans
- Off-load “unproductive” tasks
- Before, supporting, & after humans

Part 2: Neo-geography

- Automated planetary mapping
- Easy access to planetary data
- “Desktop exploration”

Part 3: Exploration GDS

- Reusable software tools for distributed science operations
- Web-based & open standards
- Plan, monitor, explore

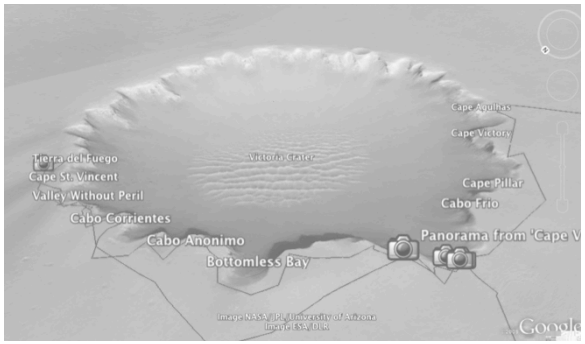
New Ways of Exploring

Part 1: Robots for human exploration

- Complement & supplement humans
- Off-load “unproductive” tasks
- Before, supporting, & after humans

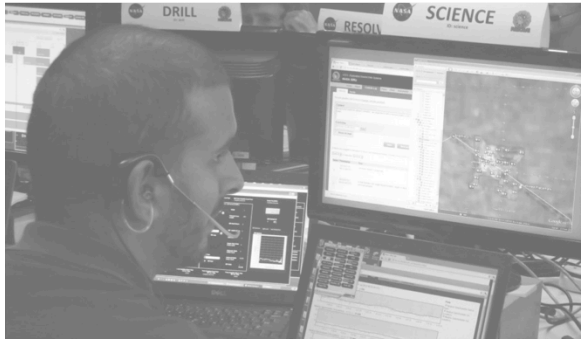
Part 2: Neo-geography

- Automated planetary mapping
- Easy access to planetary data
- “Desktop exploration”



Part 3: Exploration GDS

- Reusable software tools for distributed science operations
- Web-based & open standards
- Plan, monitor, explore



Part 1: Robots for Human Exploration

Robots before crew

- Scouting, prospecting, etc.
- Site prep., equipment deploy, etc.

Robots supporting crew

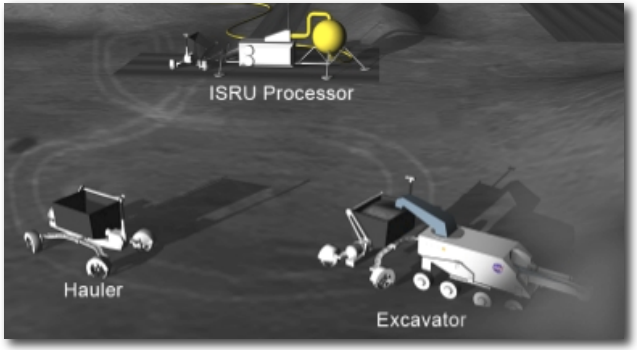
- Inspection, mobile camera, etc.
- Heavy transport & mobility

Robots after crew

- Follow-up & “caretaking” work
- Close-out tasks, maintenance, etc.

Human-robot teaming

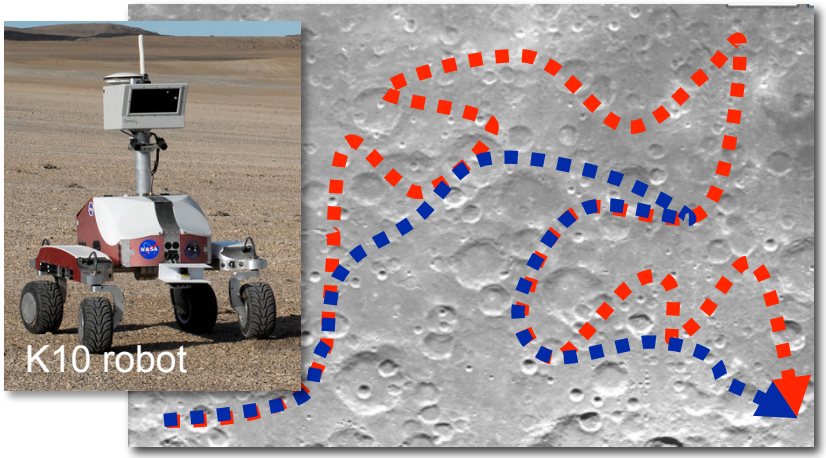
- **Coordination**
- **Cooperation**
- **Collaboration**



Robotic Recon Experiment

Objectives

- Test robotic recon ahead of crew
- Test coordinated human-robot field exploration
- Fold lessons learned into lunar surface science ops concepts

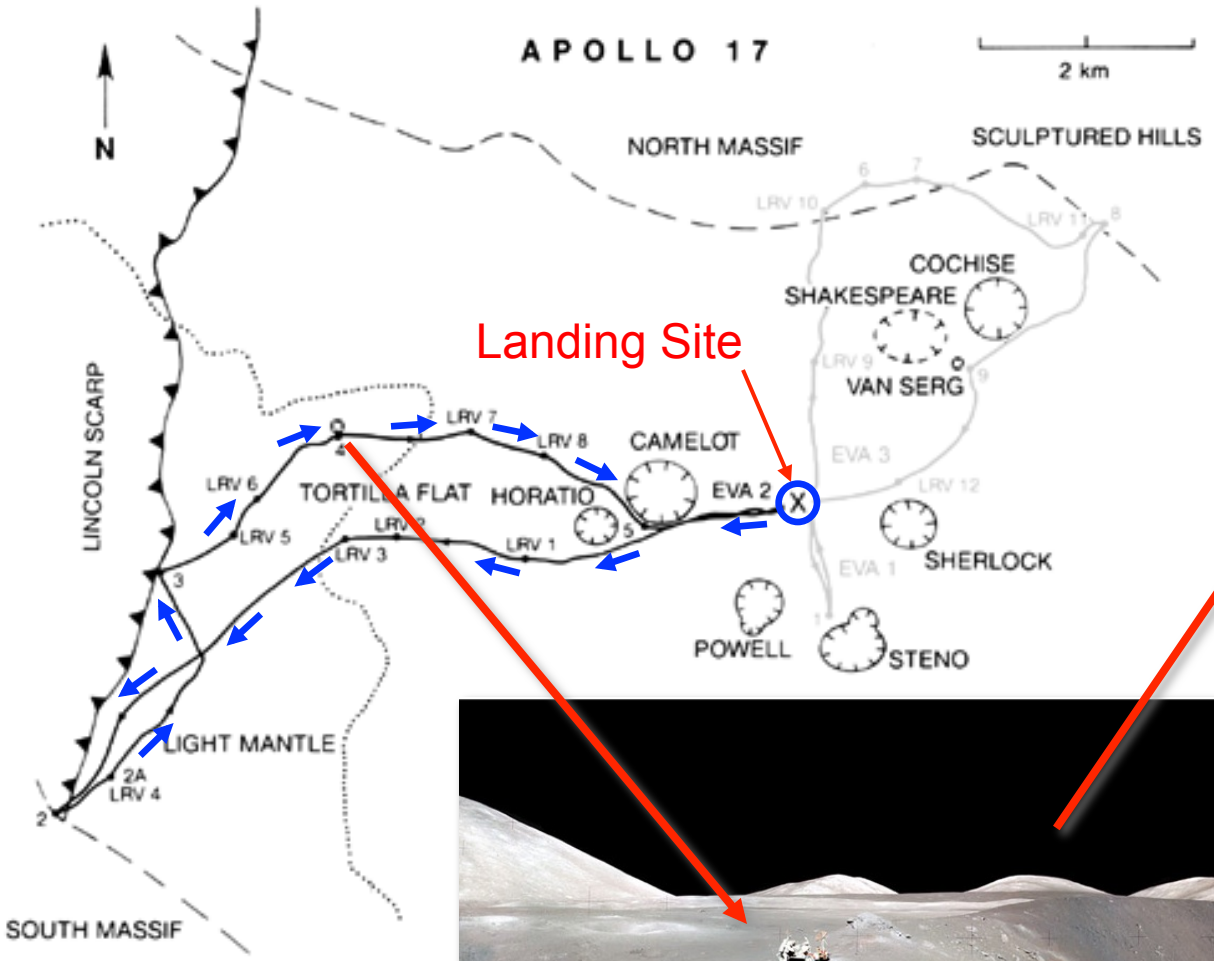


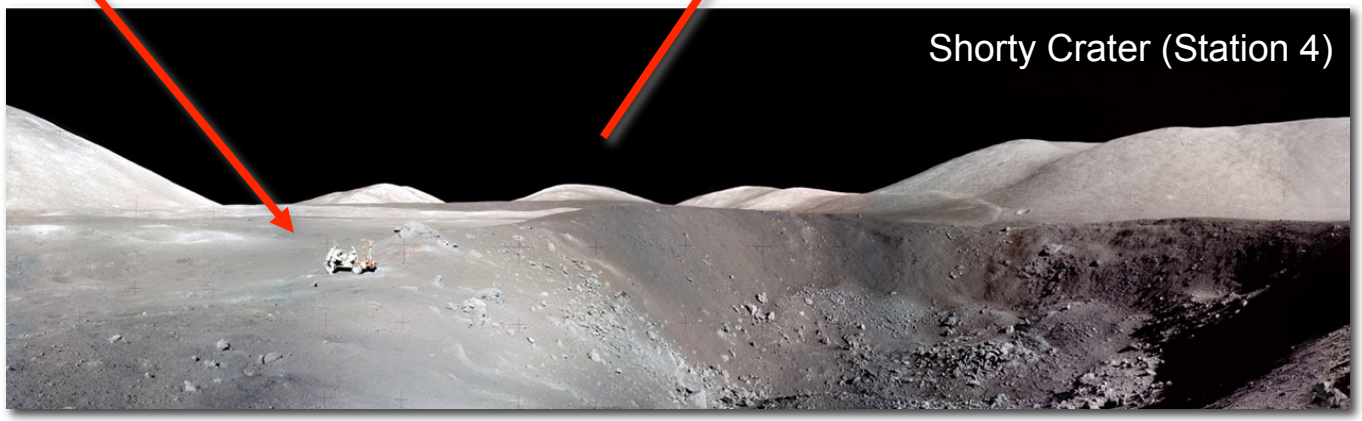
Results

- Captured requirements (instruments, comm, nav, etc.) for robotic recon
- Assessed impact of robotic recon on traverse planning & crew productivity
- Learned how to improve human productivity & science return

M. Bualat et al. (2011). Robotic recon for human exploration: method, assessment, and lessons learned. GSA Special Paper.

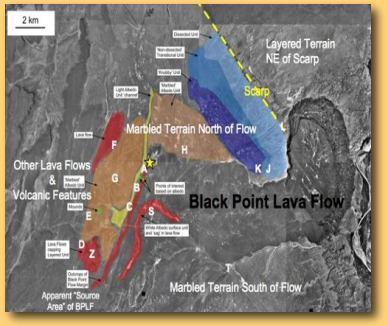
Why Is Recon Useful?





Field Experiment (2009)

Pre-Recon



Mar 1 – June 1

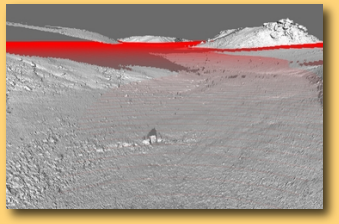
- Satellite images
- Geologic map

Robot Mission

June 14 – 26

- K10 at BPLF
- Ground control at NASA Ames

Pre-Crew



July 1 – Aug 15

- Recon images
- Terrain models

Crew Mission

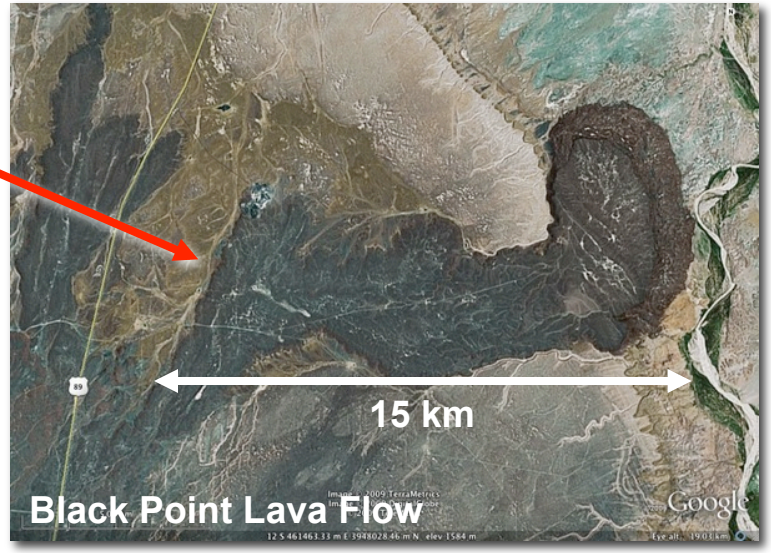
Aug 29 – Sep 3

- SEV at Black Point
- Science backroom at Black Point

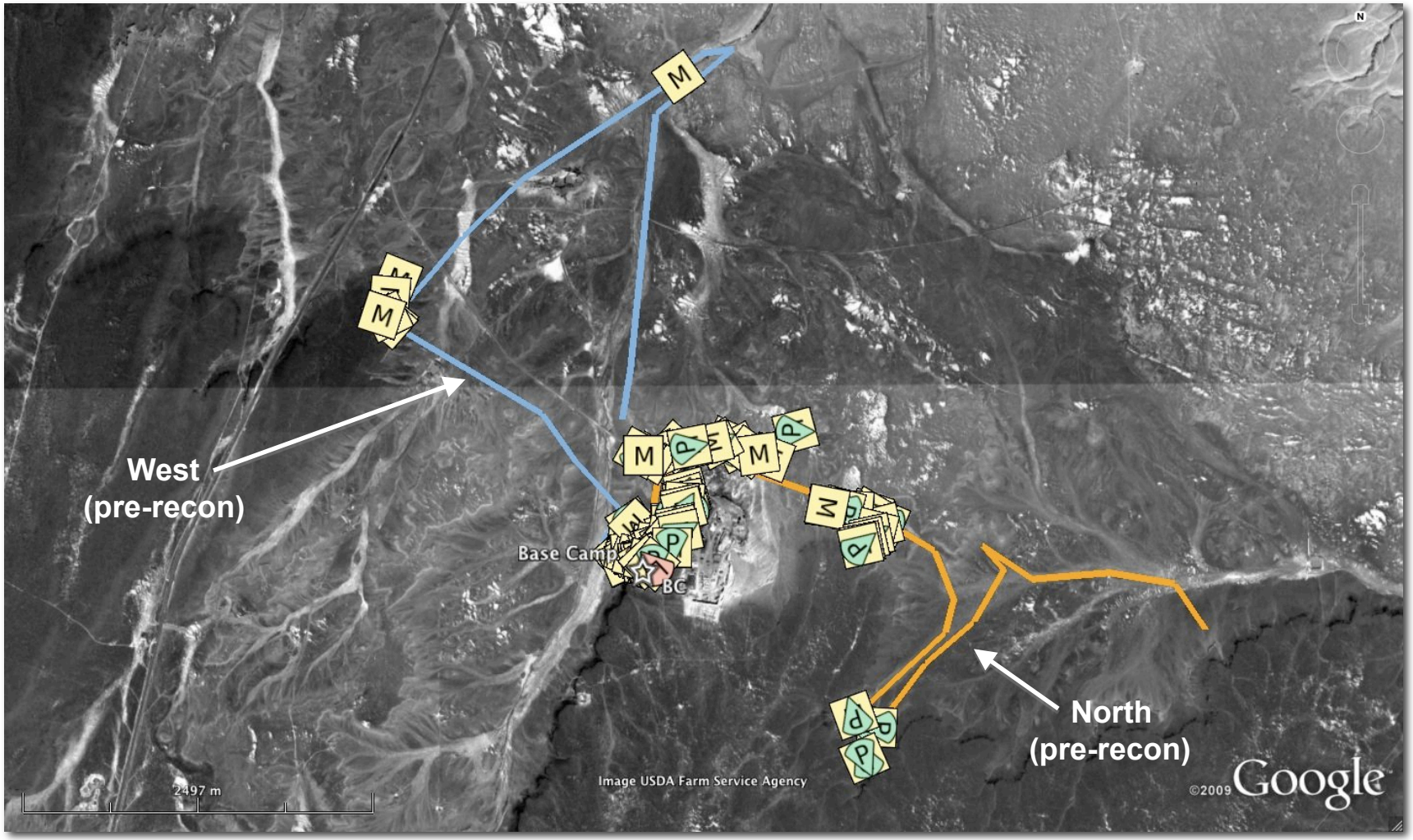
Lunar Analog Site: Black Point Lava Flow

Black Point Lava Flow

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



Collected Recon Data

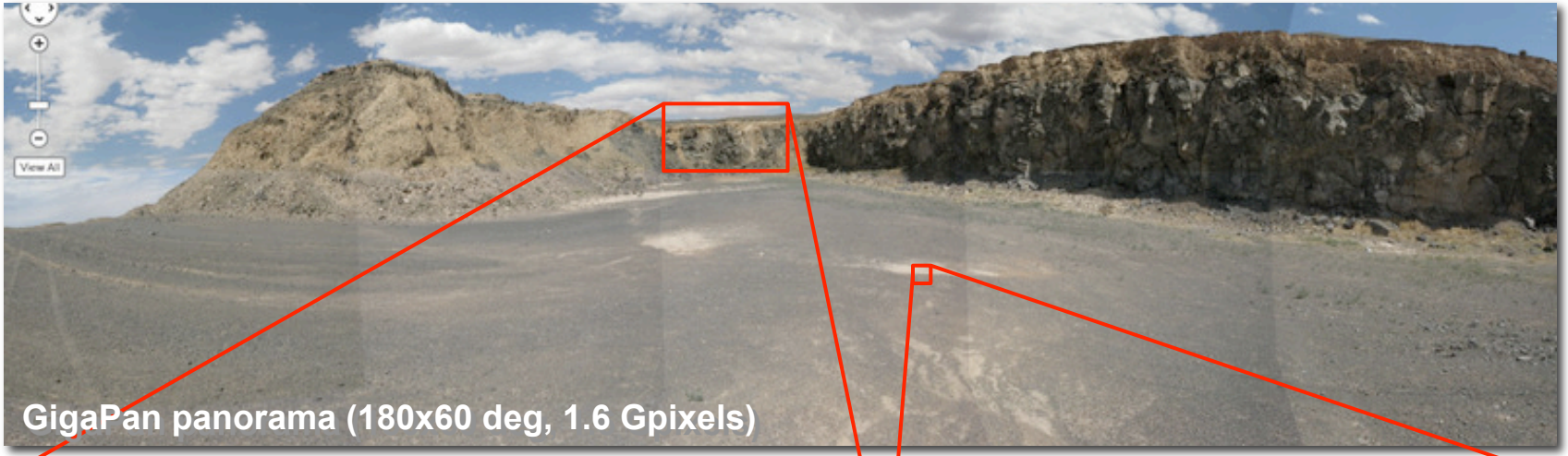


8.5 GB data collected (52 hrs of robotic recon operations)
39 LIDAR scans, 75 GigaPan, and 95 terrain images

Orbital Data

Digital Globe QuickBird (60 cm/pixel)

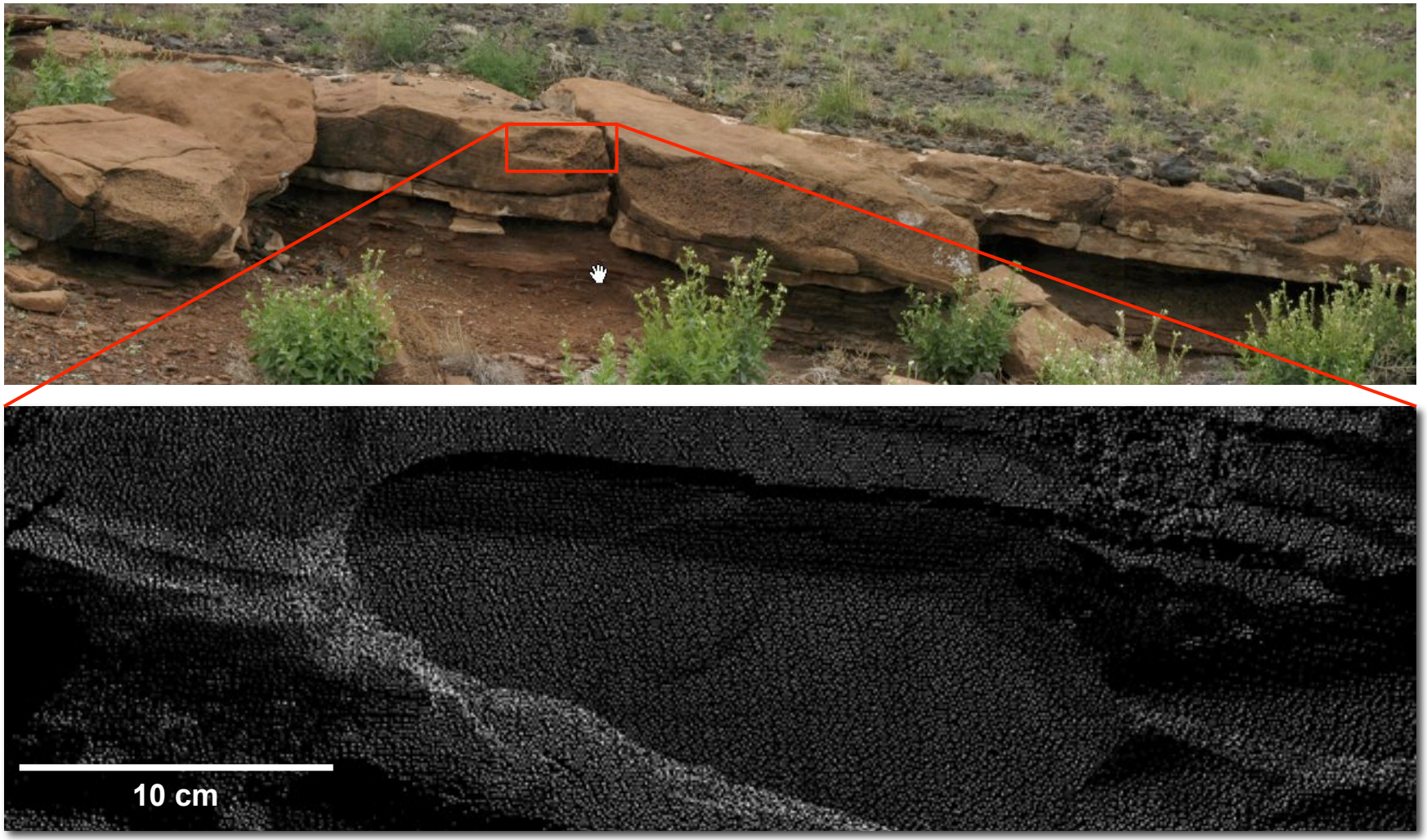
Surface Data



GigaPan panorama close-up

Terrain image (55 microns / pixel)

Surface Data



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

Crew Mission

Space Exploration Vehicle (SEV)

- Prototype pressurized crew vehicle for lunar operations
- Two “suit ports” for rapid (15 min) egress and ingress
- 20 km/hr max, active suspension
- 3.5 x 5 m (wheelbase x length)

Crew A

- Mike Gernhardt & Brent Garry
- W1 (pre-recon) + N2 (post-recon) traverses

Crew B

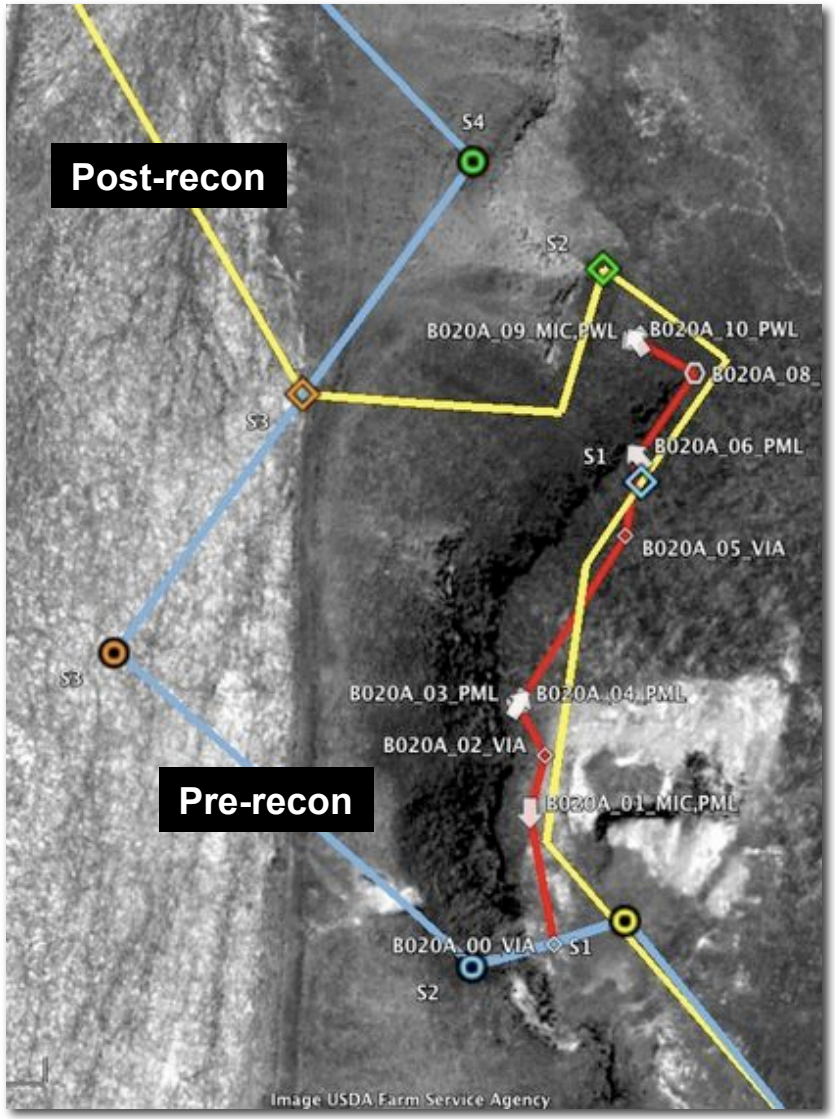
- Andy Thomas & Jake Bleacher
- N1 (pre-recon) + W2 (post-recon) traverses

Robotic Recon Results

"West" region

- **Pre-recon** plan was designed to be Apollo-like
  - Rapid area coverage (visit 5 geologic units)
  - Single visit
- **Post-recon** plan is significantly different
  - More flexible & adaptable
  - Recon data supports real-time replanning
- Impact of recon
  - Reduced science uncertainty
  - Improved target prioritization

T. Fong et al. (2010). Assessment of robotic recon for human exploration of the Moon. Acta Astronautica 67 (9-10)



Robotic Follow-up Experiment

An exploration problem

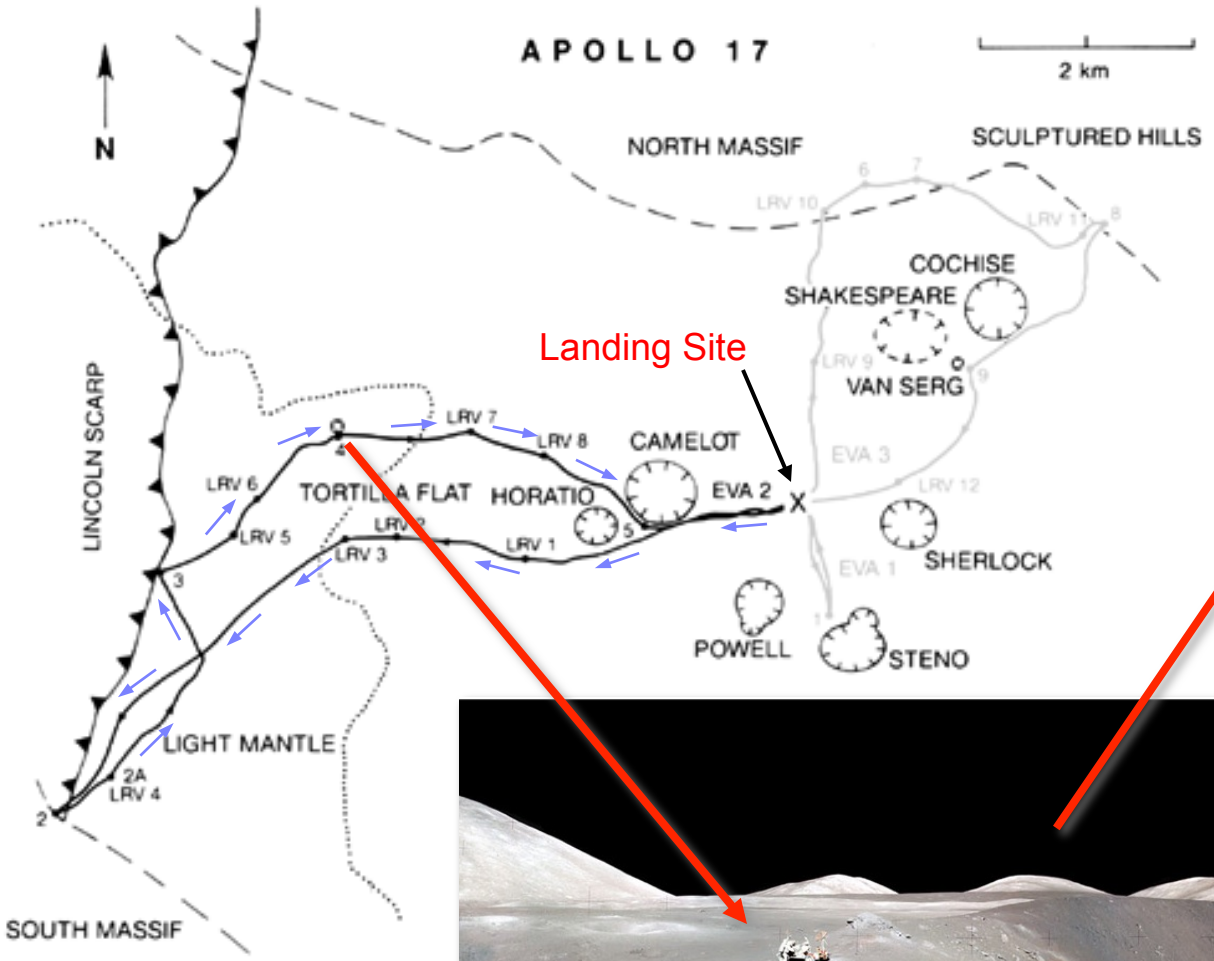
- Never enough time for field work
- "If only I could have…"
  - More observations
  - Additional sampling
  - Complementary & supplementary work

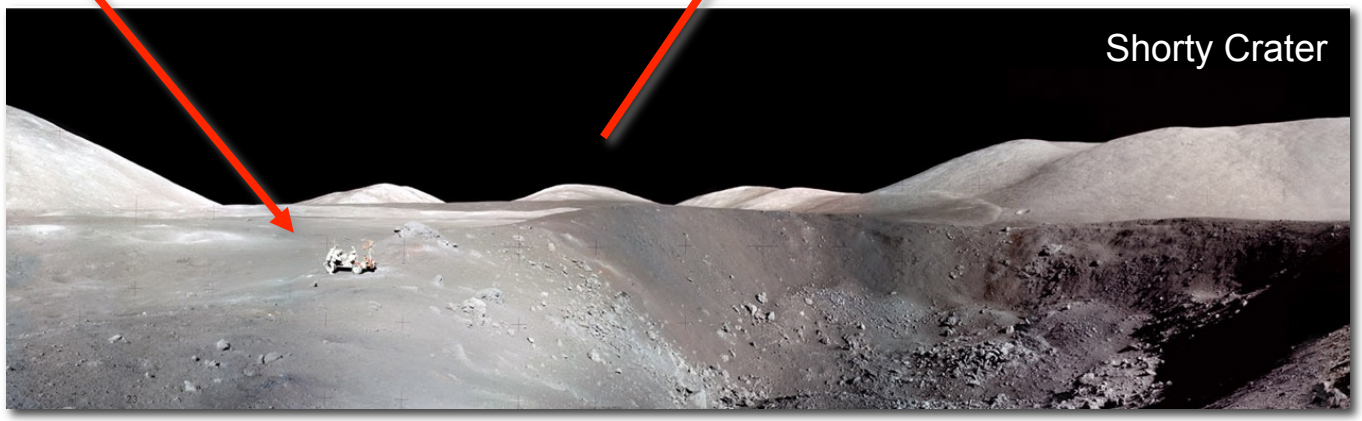
The solution

- Use robots to "follow-up" after humans
- Augment human field work with subsequent robot activity
- Use robots for work that is tedious or unproductive for humans to do

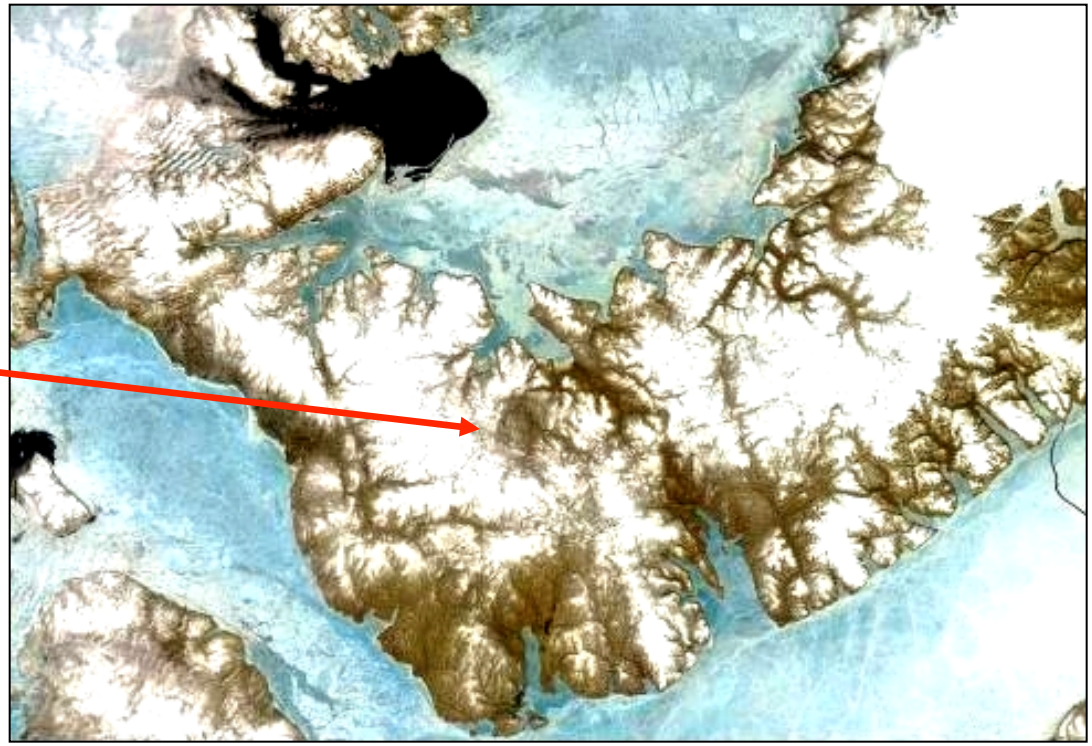
M. Deans et al. (2011). Field testing robotic follow-up for exploration field work. Proc. of the Lunar & Planetary Science Conf.

Why is Follow-up Useful?



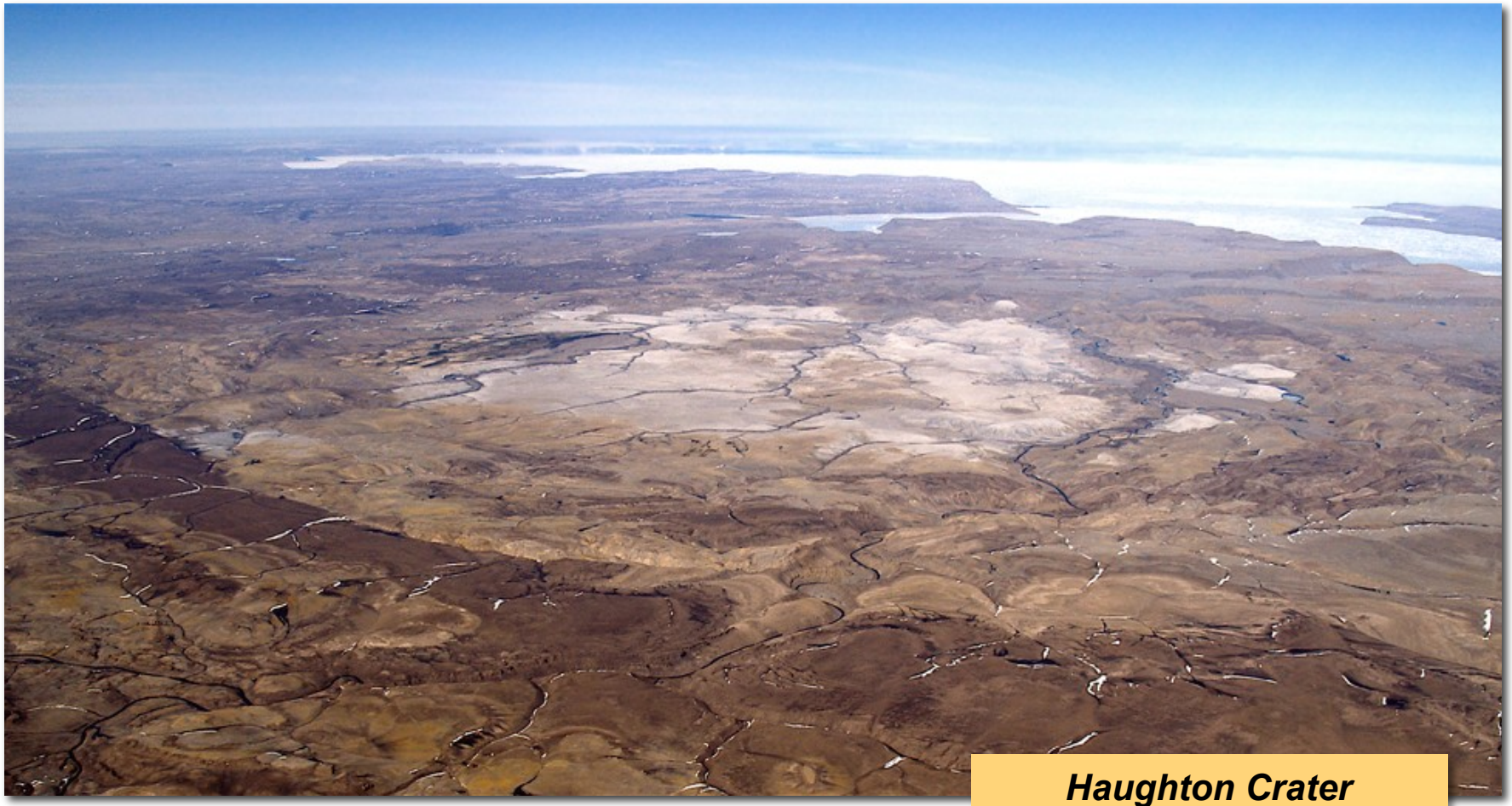


Lunar Analog Site: Haughton Crater



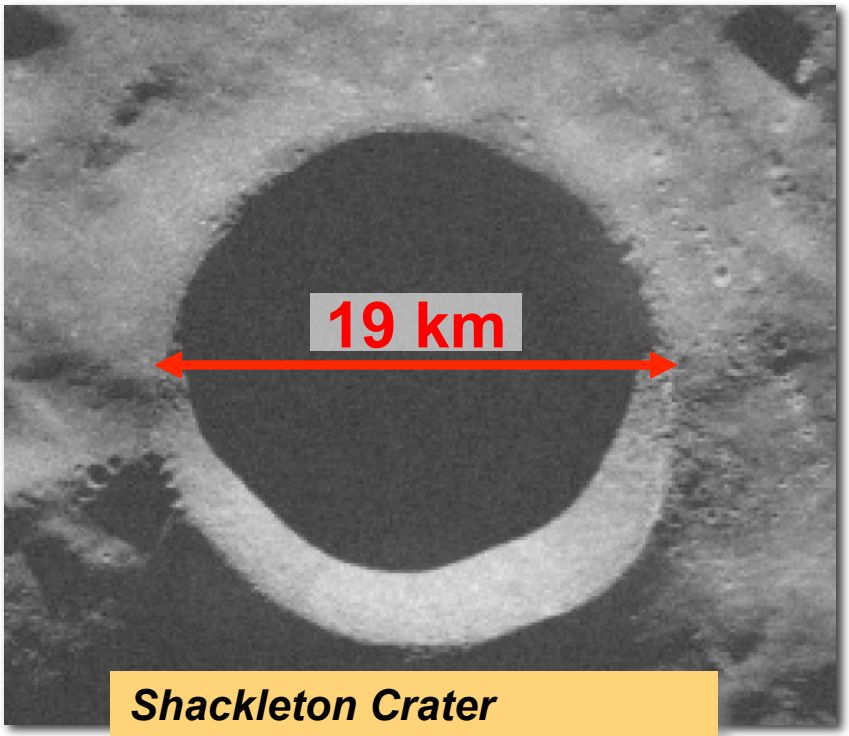
- Devon Island: 66,800 sq. km
- Largest uninhabited island on Earth
- Haughton Crater: ~20 km (diameter), ~39 Ma (Late Eocene)

Haughton Crater

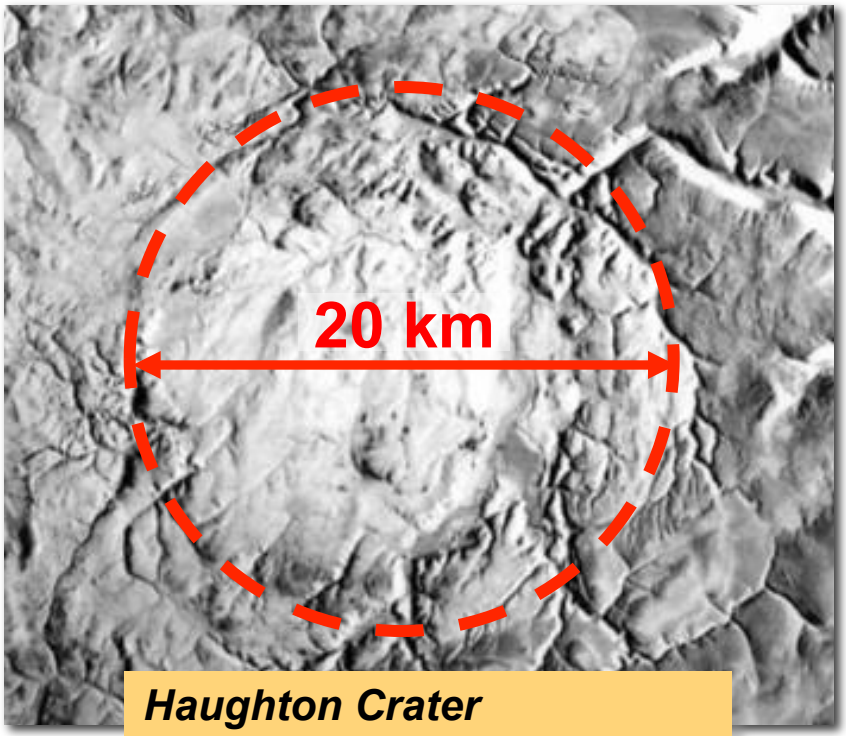


Haughton Crater
(75º 22' N, 89º 41' W)

Haughton Crater



Shackleton Crater
2005 Arecibo radar image



Haughton Crater
radar image

- Polar impact structures: mixed impact rocks & ejecta blocks
- Subsurface water ice
- Remote, isolated, difficult to access

Crew Mission (July 2009)

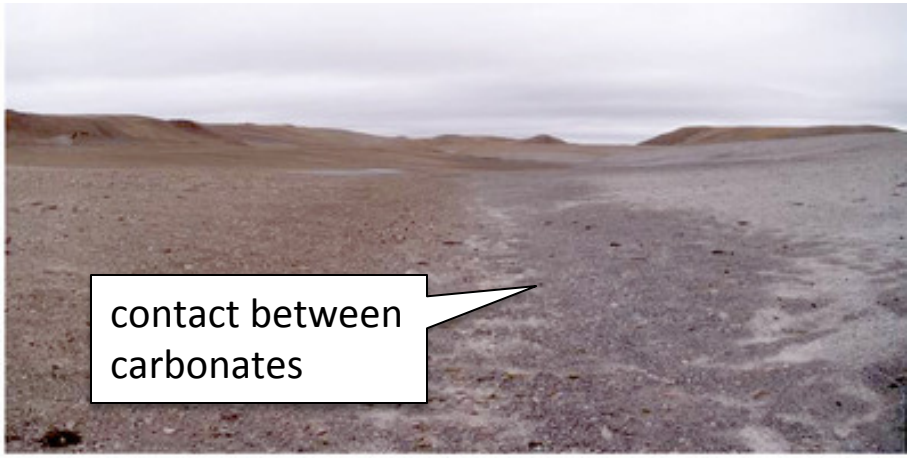
Geologic Mapping

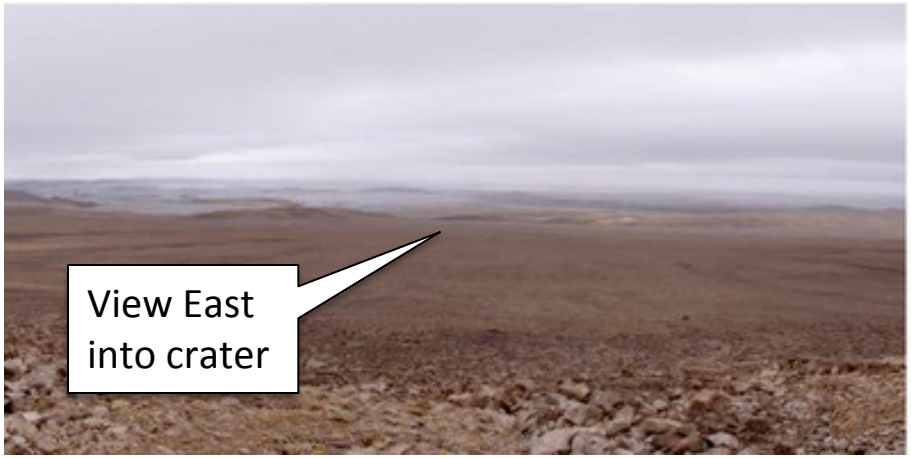
- Document geologic history, structural geometry & major units
- Example impact breccia & clasts
- Take photos & collect samples

Geophysical Survey

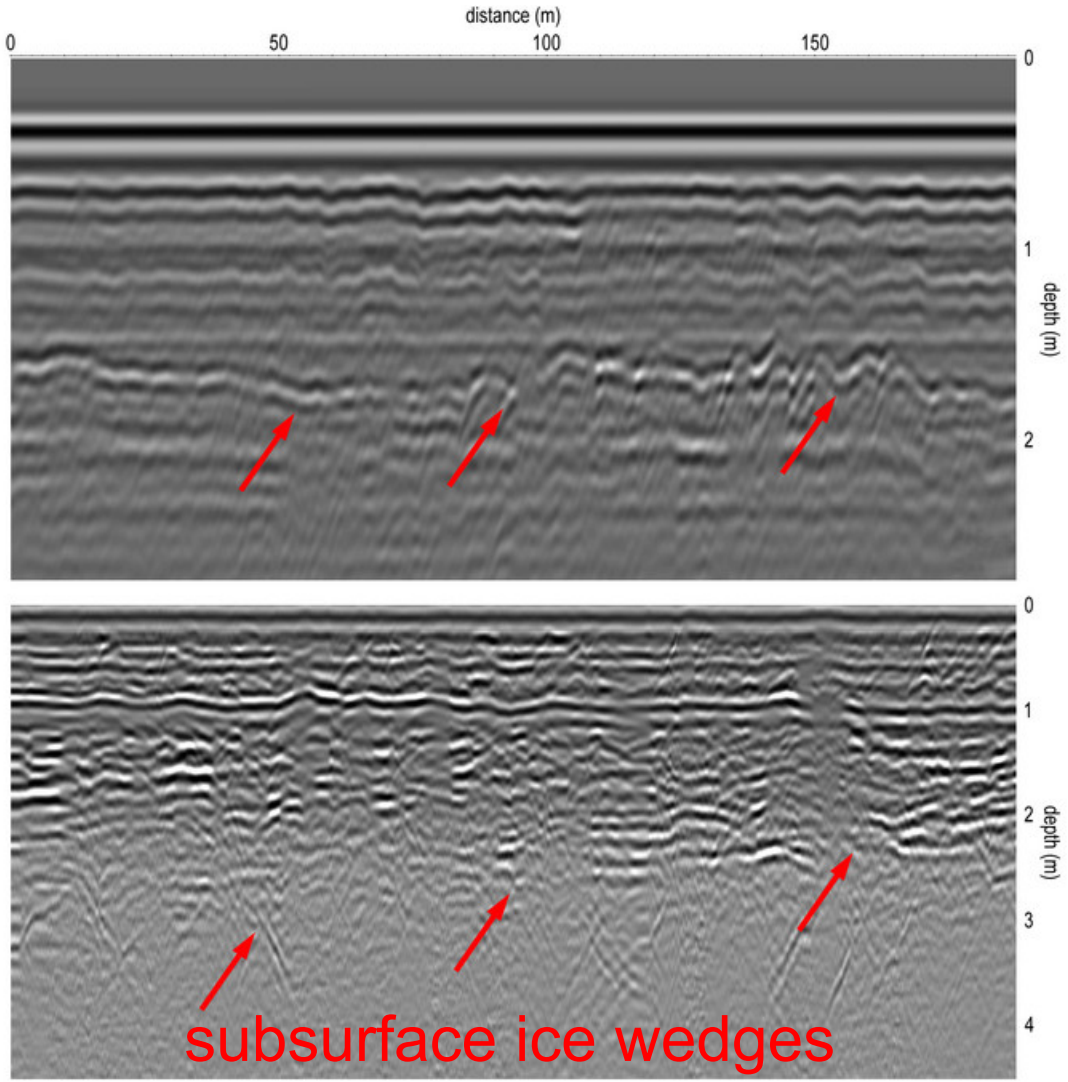
- Examine subsurface structure
- 3D distribution of buried ground ice in permafrost layer
- Ground-penetrating radar: manual deploy, 400/900 MHz

Geologic Mapping

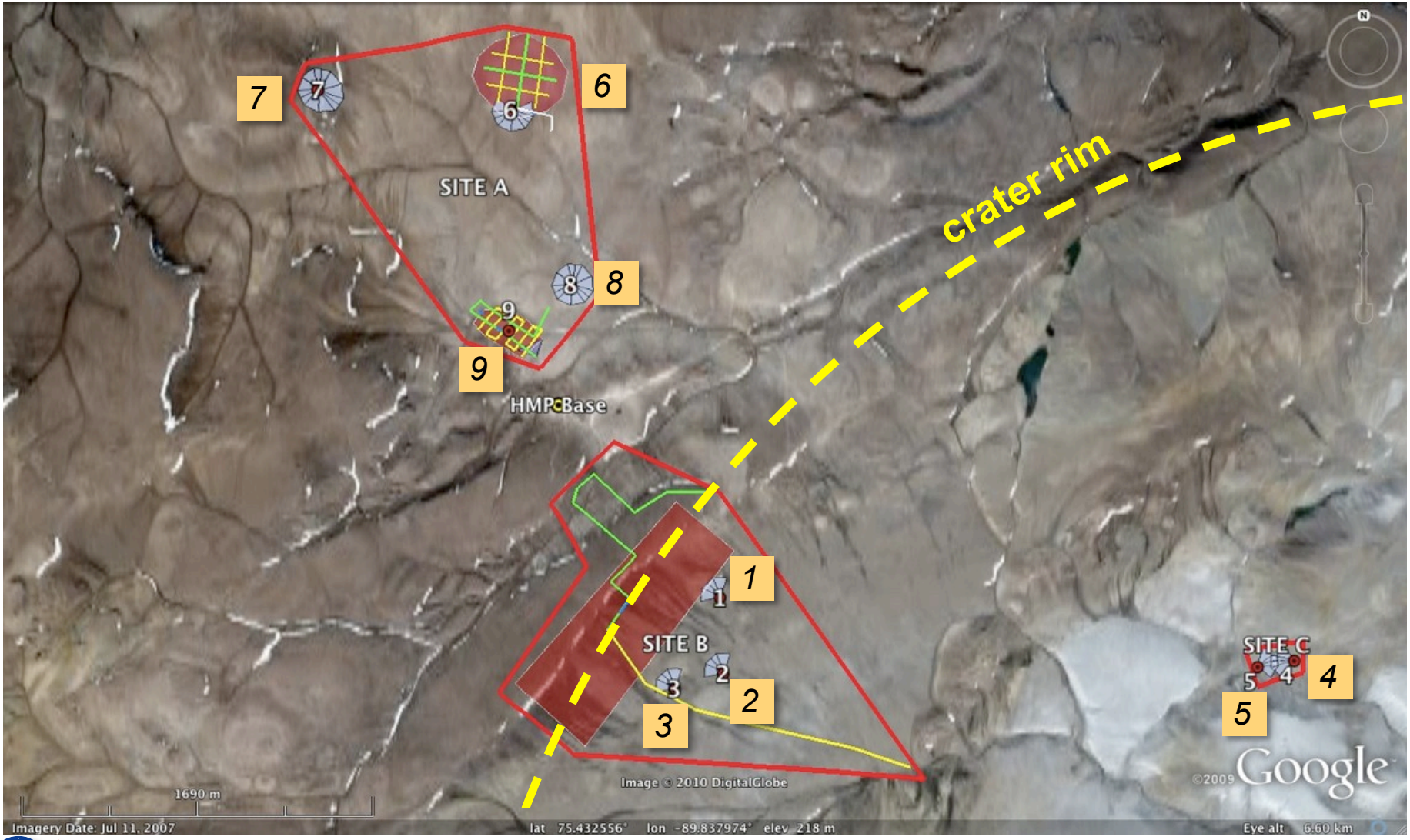




Geophysical Survey



Robotic Follow-up Plan



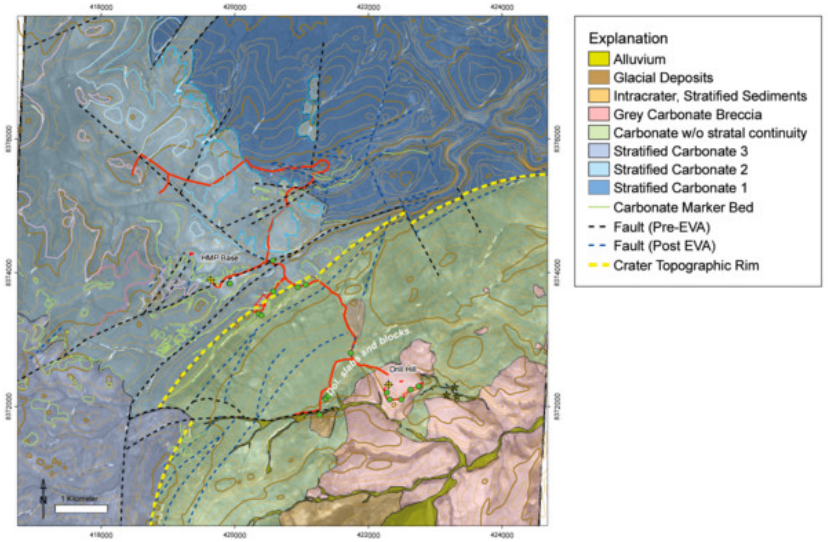
Robotic Follow-up Results

Geologic Mapping

- Verified & amended the geologic map in multiple locations
- In some places, robot data was ambiguous, or lacked sufficient detail to re-interpret the map

Geophysical Survey

- Enabled study (correlation of surface & subsurface features) of "polygons"
- Determined average depth of buried ice layer

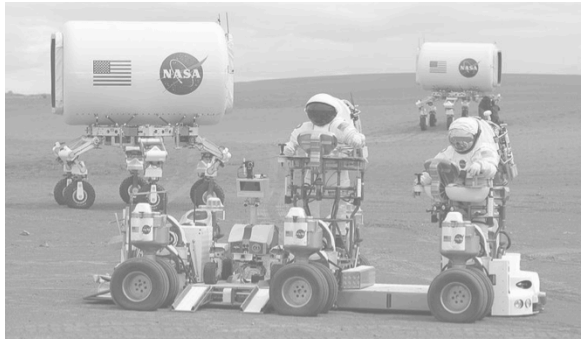


T. Fong et al. (2010). Robotic follow-up for human exploration. AIAA-2010-8605. Proc. of AIAA Space 2010.

New Ways of Exploring

Part 1: Robots for human exploration

- Complement & supplement humans
- Off-load “unproductive” tasks
- Before, supporting, & after humans

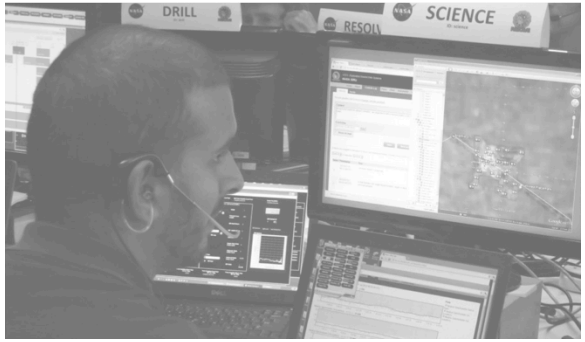


Part 2: Neo-geography

- Automated planetary mapping
- Easy access to planetary data
- “Desktop exploration”

Part 3: Exploration GDS

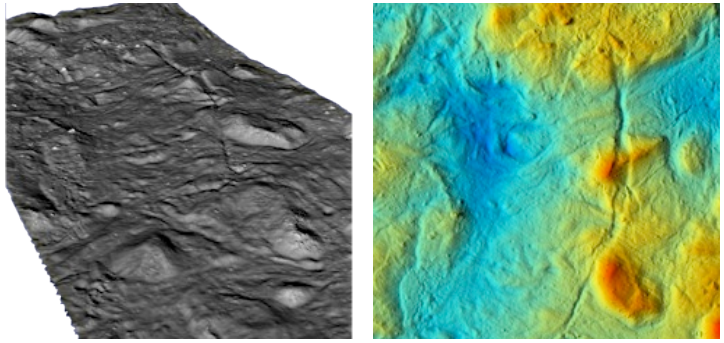
- Reusable software tools for distributed science operations
- Web-based & open standards
- Plan, monitor, explore



Part 2: Neo-Geography

Overview

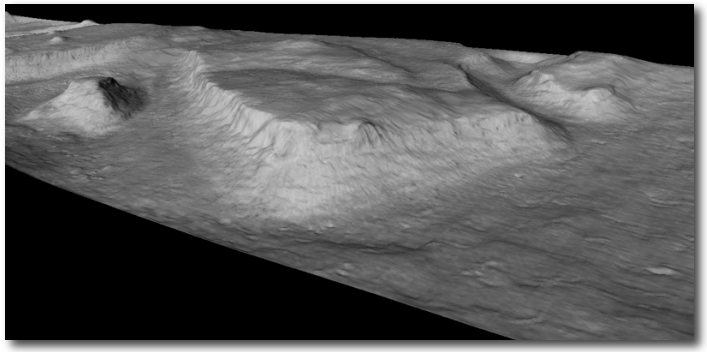
- Revolution in mapping
- Revolution in geographic tools
- **LOTS** of planetary data …



Jackson Crater, Moon

Modern planetary mapping

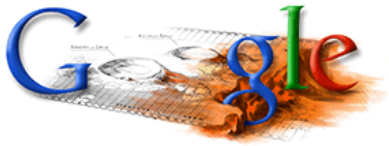
- Satellite imaging (Moon, Mars, etc.)
- Automated map processing
- Live mission data



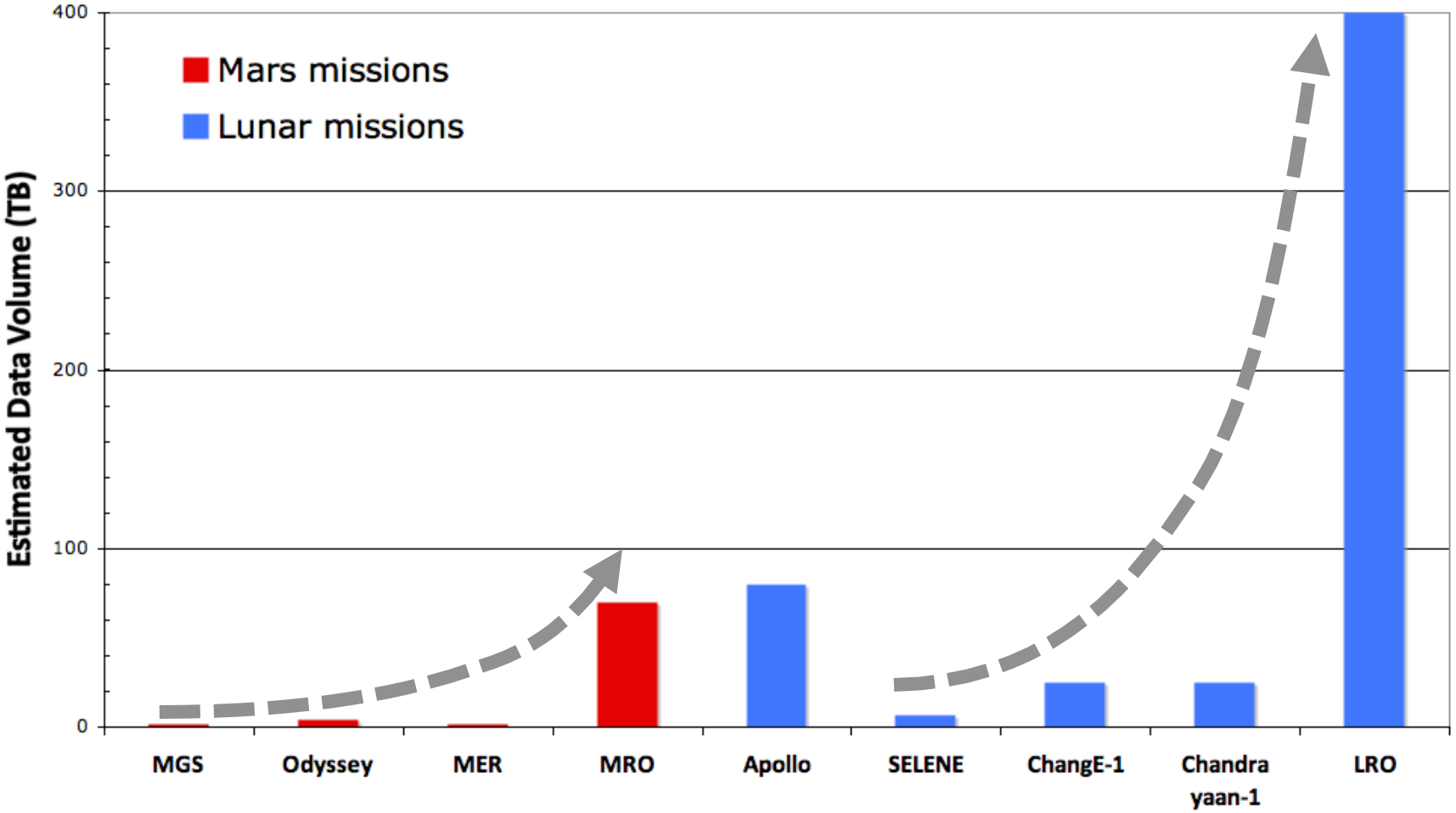
Galaxius Fluctus, Mars

Desktop exploration

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



More and More Planetary Data



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

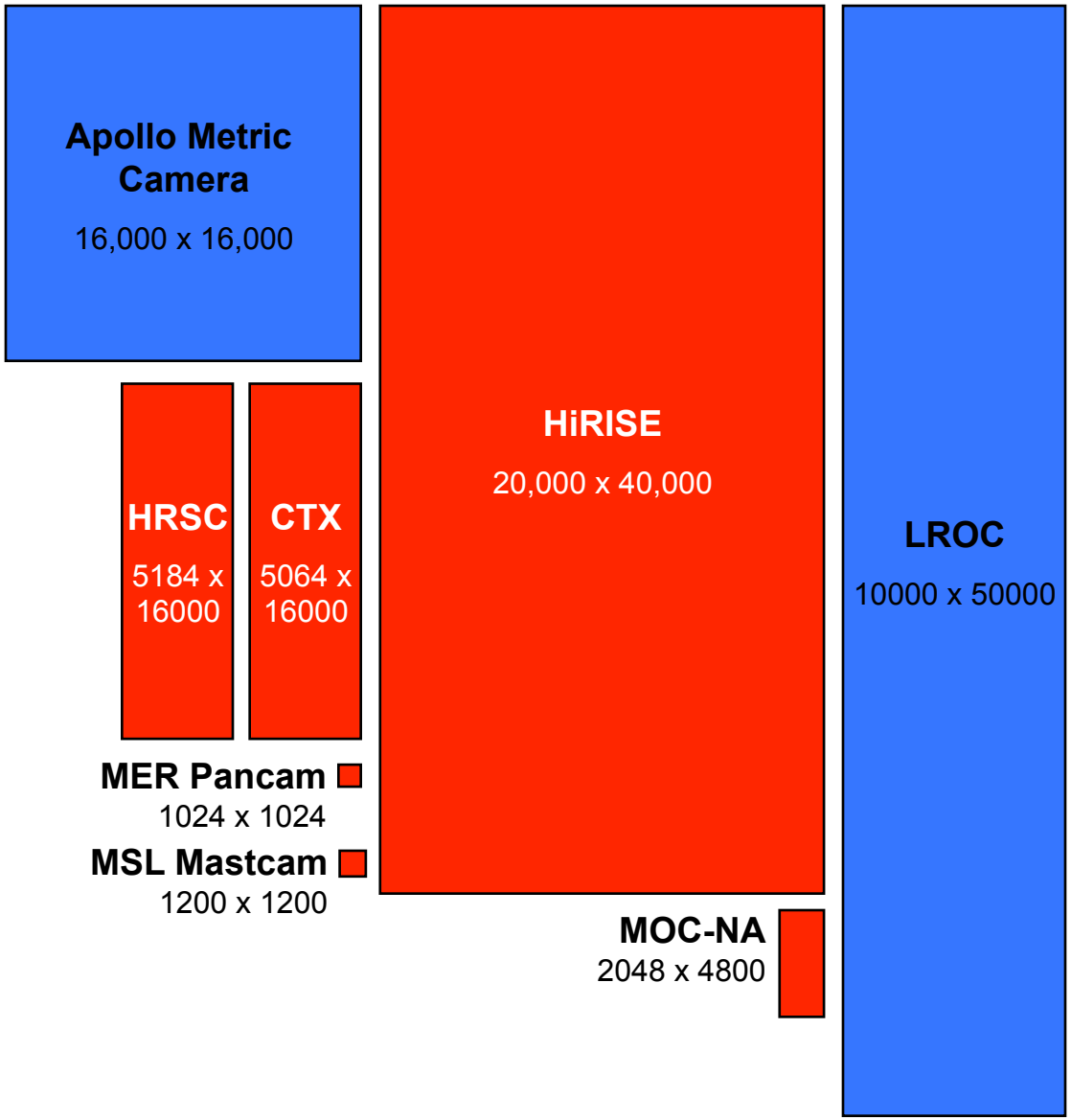
Really Big Images

Traditional mapping

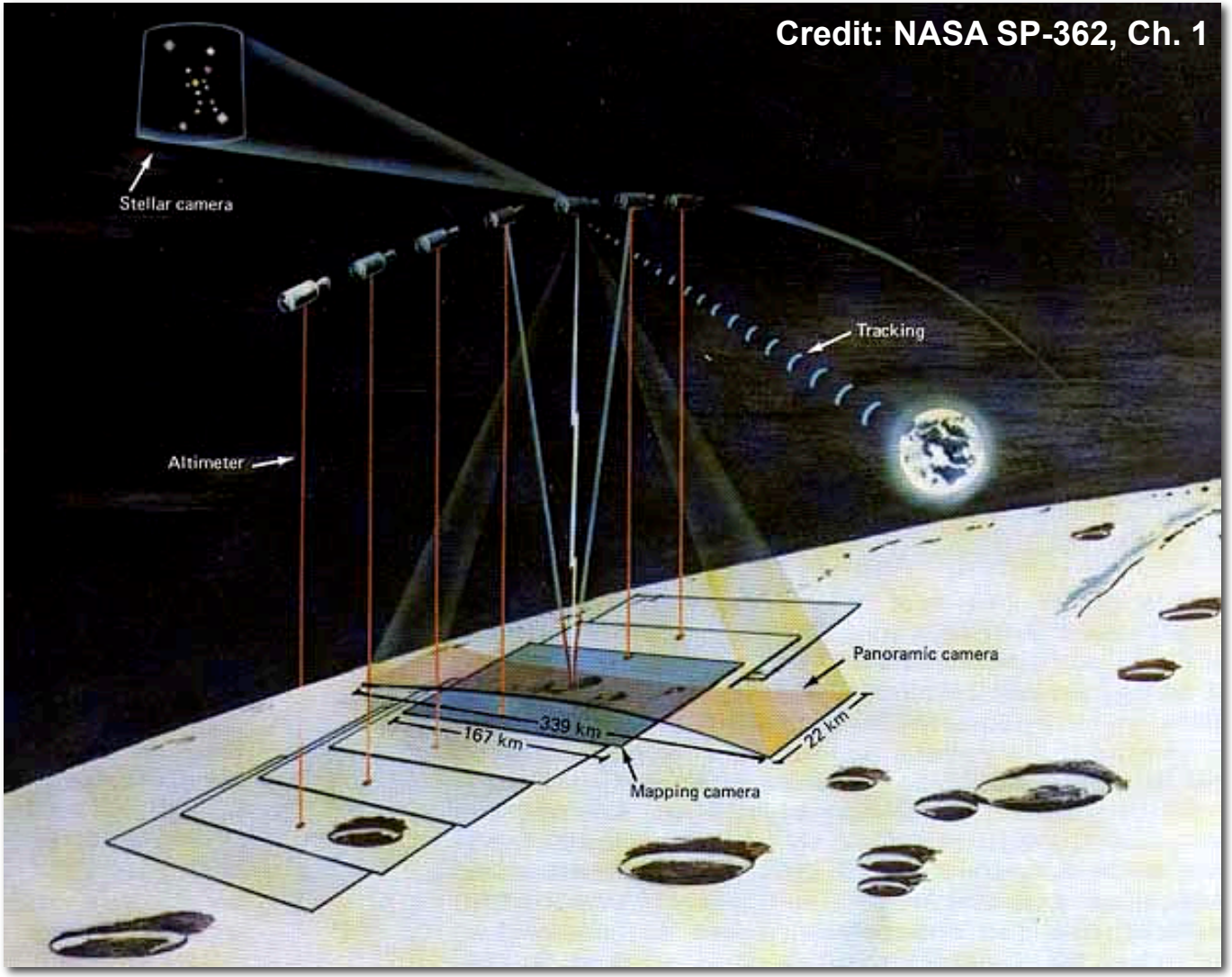
- Human-intensive cartography
- Manual control & error analysis
- Maps take years to complete

Digital imagery

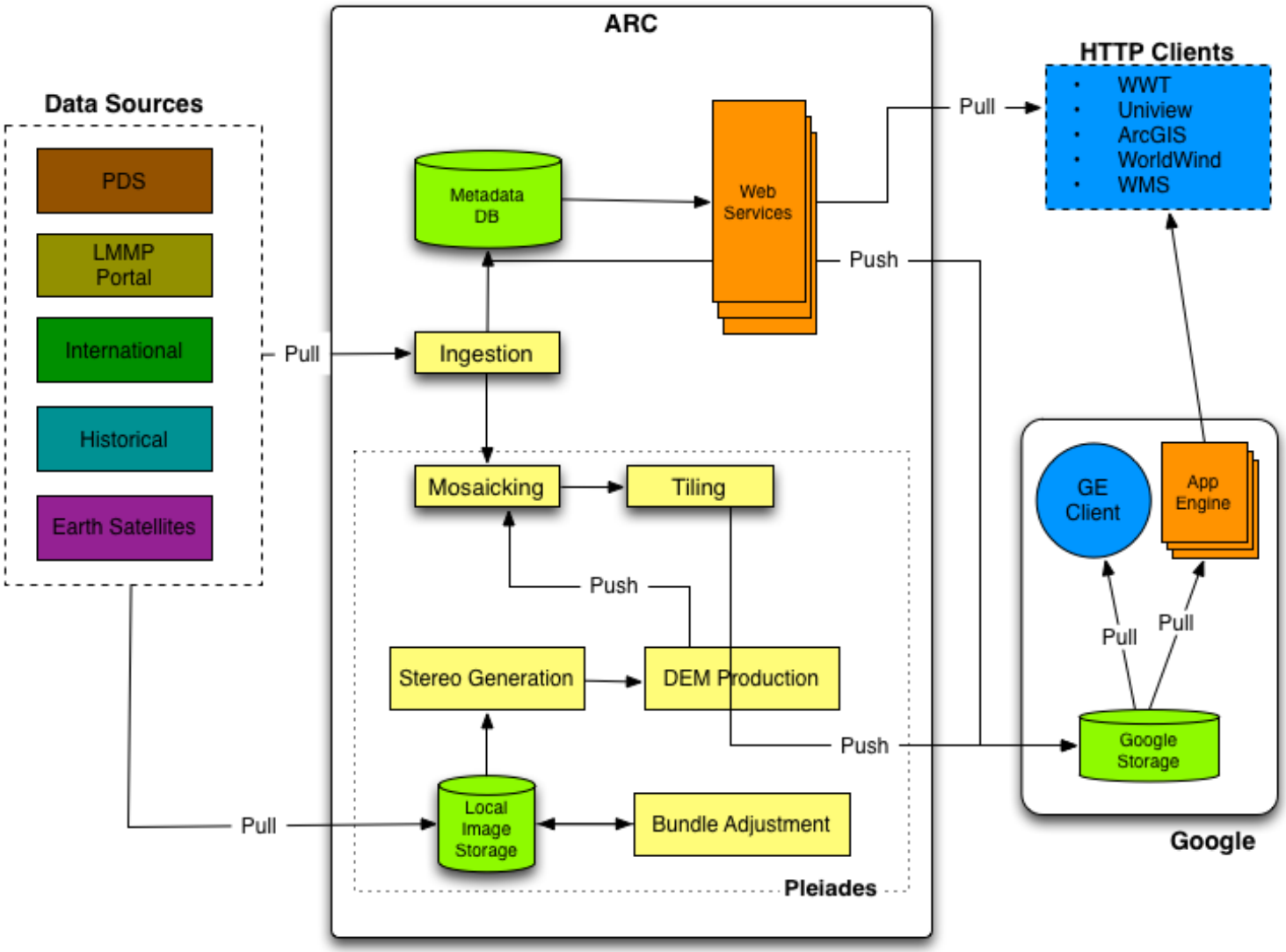
- Cameras keep getting better
- Higher resolution & dynamic range
- High-res digital scans of old film



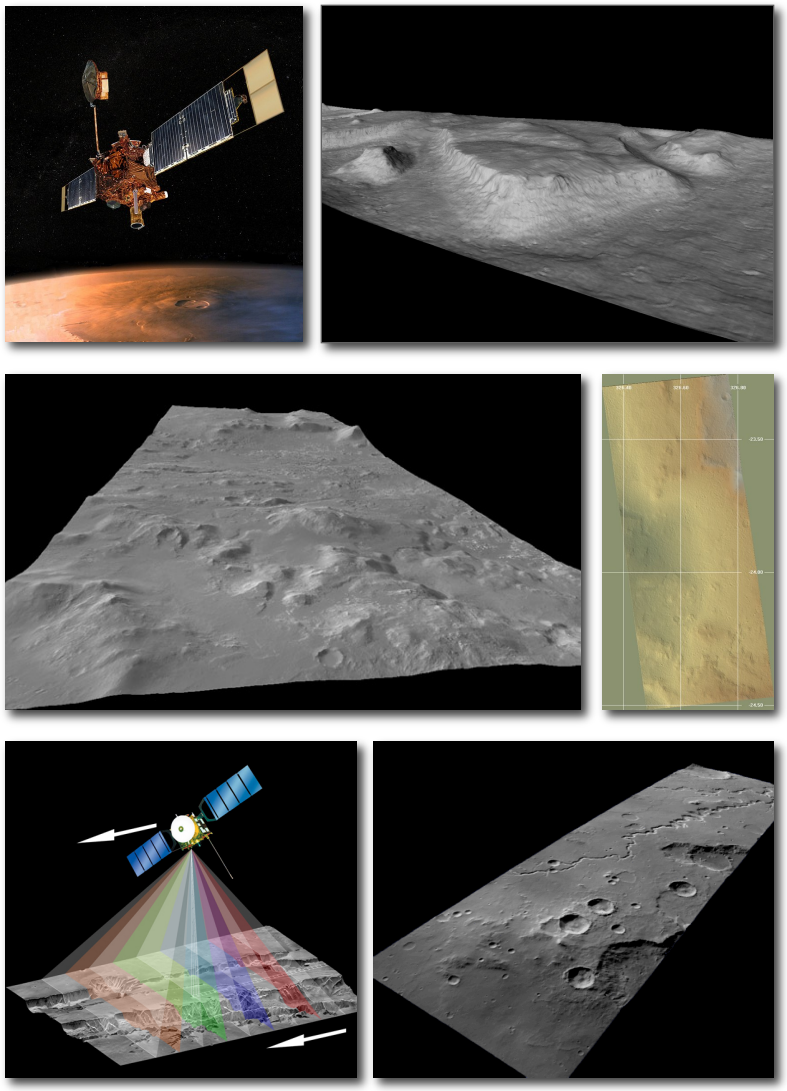
Automated Stereo Image Processing



Map Processing Pipeline



Mars Terrain Models



MGS MOC Narrow Angle

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

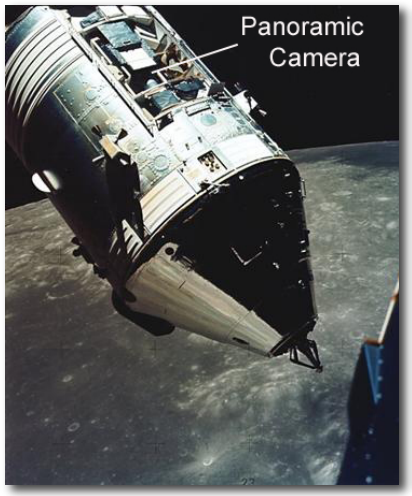
MRO Context Imager (CTX)

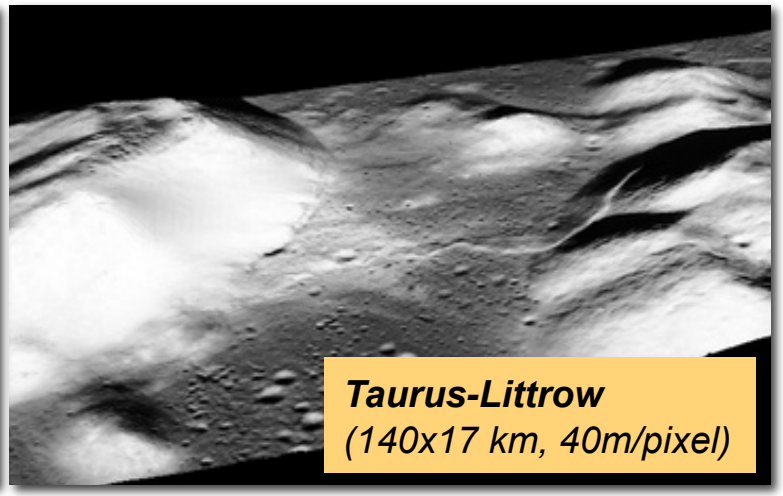
- Collaboration with CTX Team
- Provided rapid turn-around stereo modeling

Mars Express HRSC

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

Lunar Terrain Models



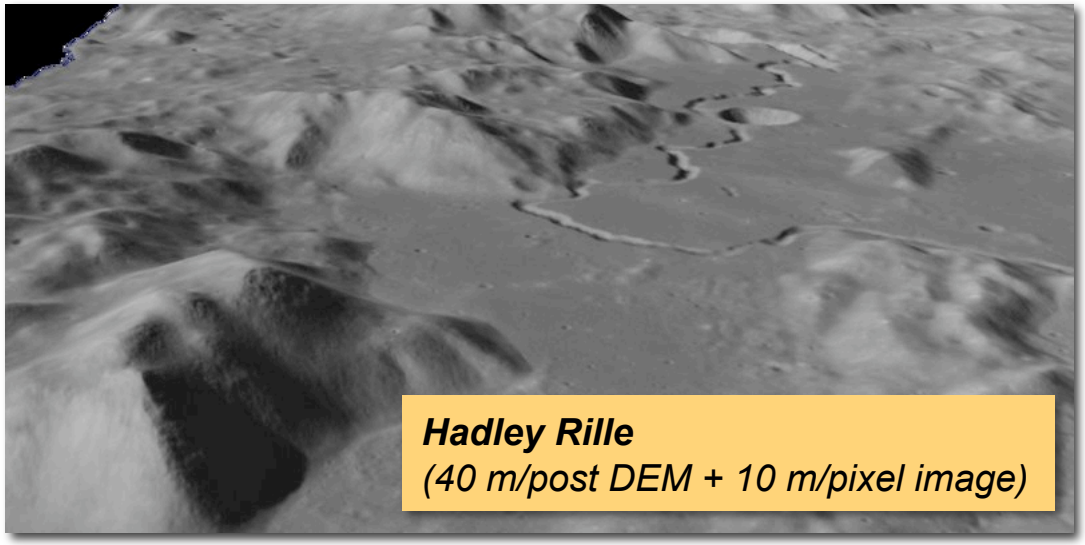


Apollo Panoramic Camera

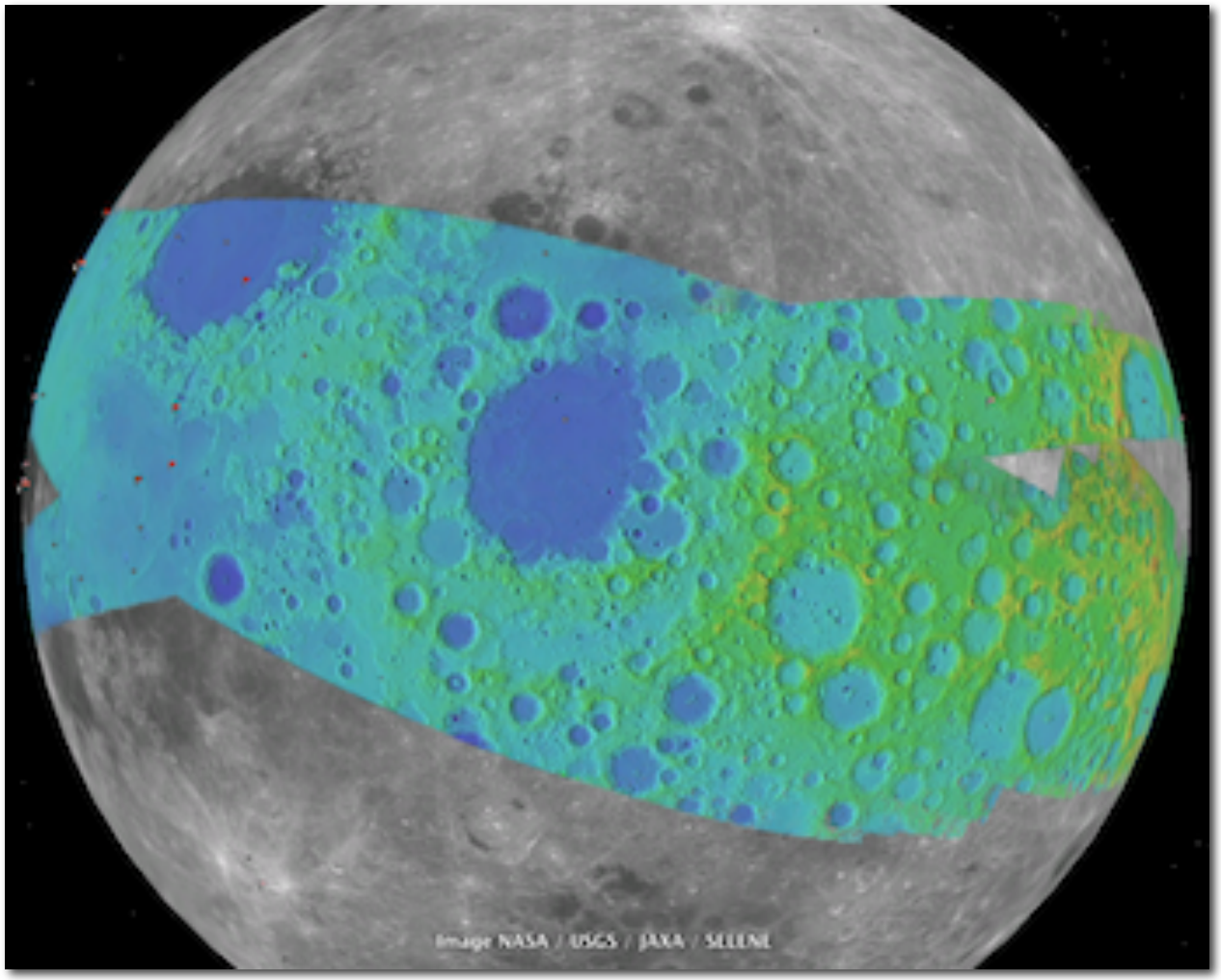
- 3D terrain model of Taurus-Littrow valley (Apollo 17)
- Featured at the Hayden Planetarium (American Museum of Nat. History)

Apollo Metric Camera

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



Apollo Zone Digital Elevation Map (DEM)



Mosaick of 4,000 images

- Apollo Metric Camera
- 73,728 x 368,640 pixels

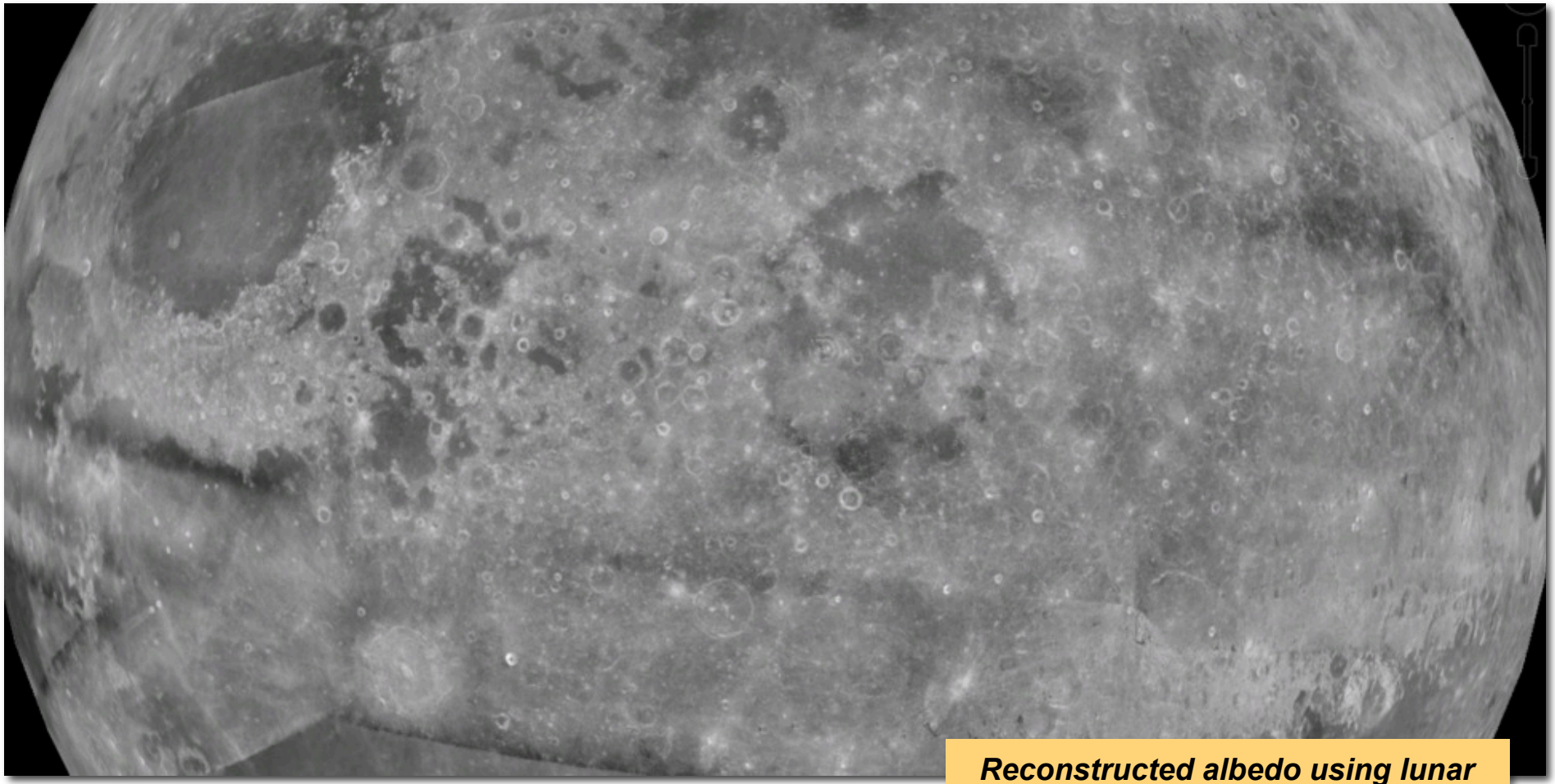
Equatorial Lunar Surface (38S-34N lat)

- 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 Pleiades supercomputer)

Apollo Zone Digital Image Mosaick (DIM)



Reconstructed albedo using lunar Lambertian reflectance model

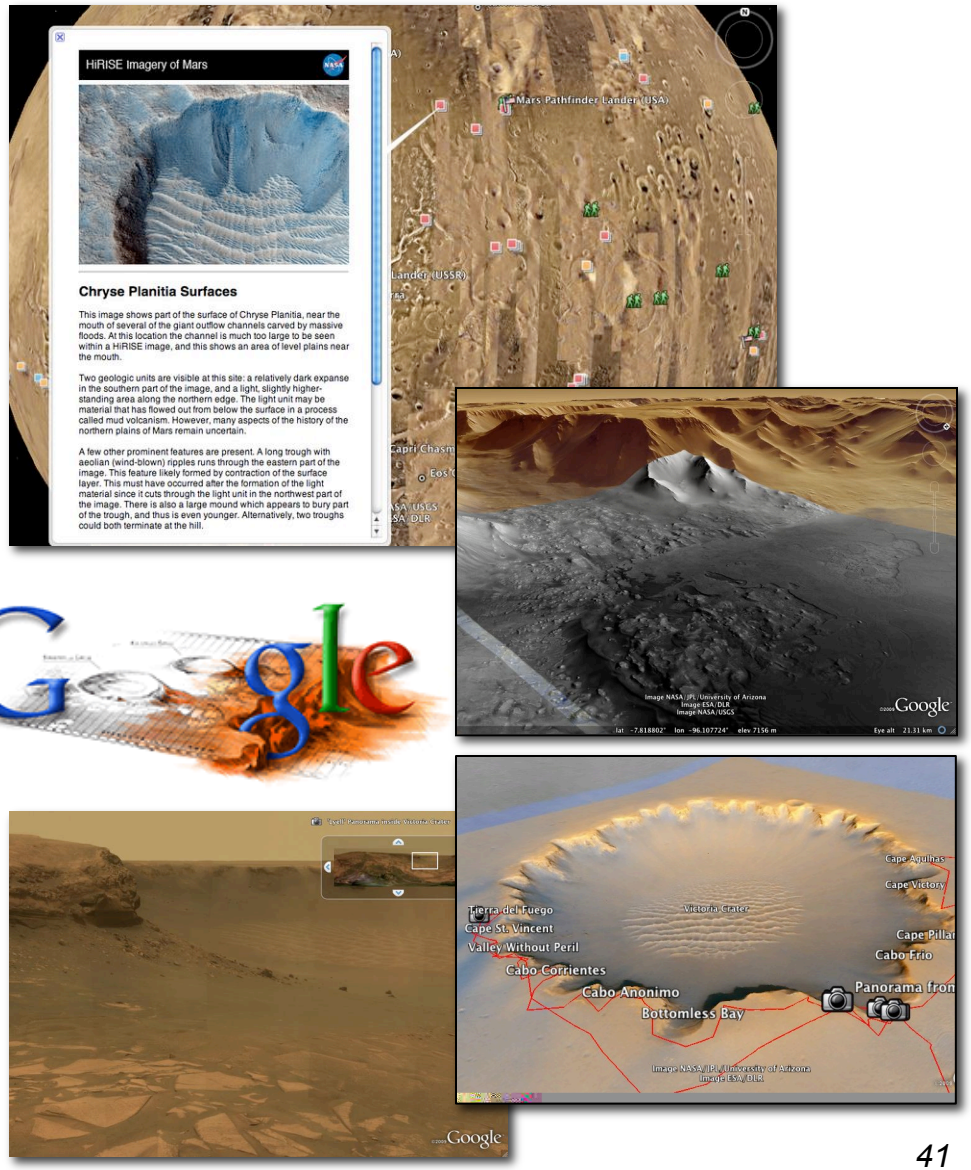
Mars in Google Earth

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 …



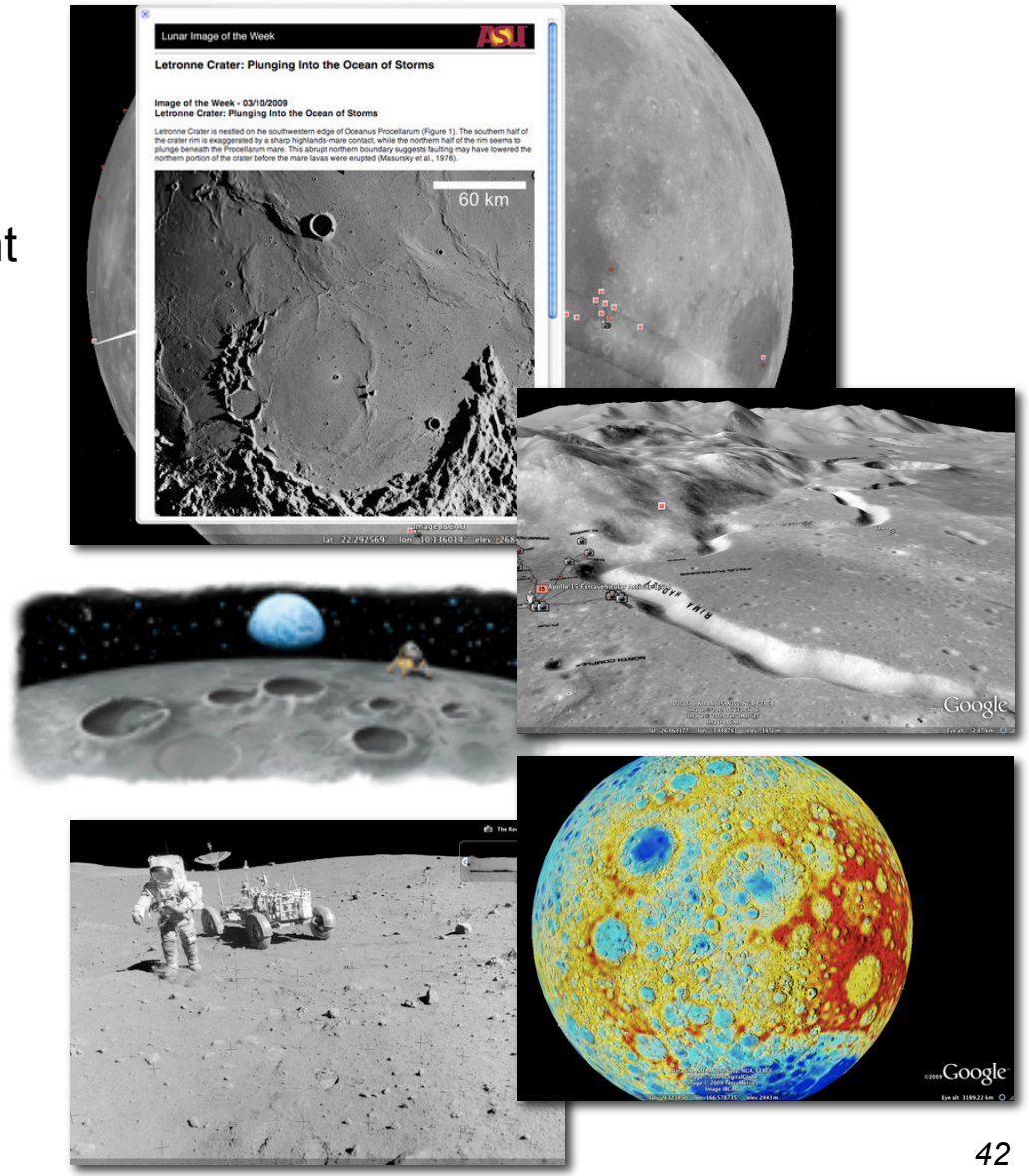
Moon in Google Earth

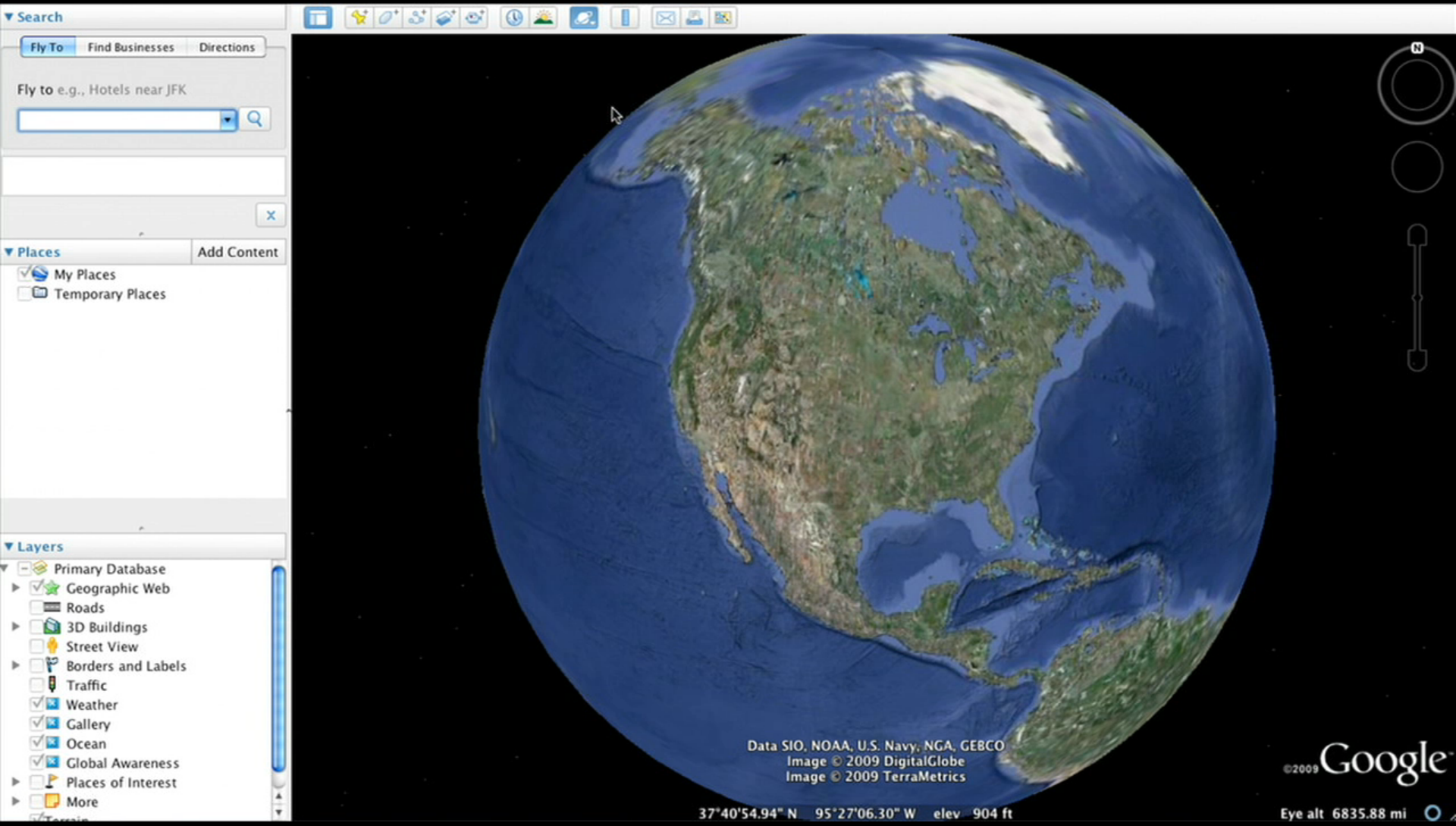
Explore the Moon in 3D

- 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 …




Search
Fly To
Find Businesses
Directions
Fly to e.g., Hotels near JFK
Places
Add Content
My Places
Temporary Places
Layers
Primary Database
Geographic Web
Roads
3D Buildings
Street View
Borders and Labels
Traffic
Weather
Gallery
Ocean
Global Awareness
Places of Interest
More
N
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2009 DigitalGlobe
Image © 2009 TerraMetrics
©2009 Google
37°40'54.94" N 95°27'06.30" W elev 904 ft
Eye alt 6835.88 mi

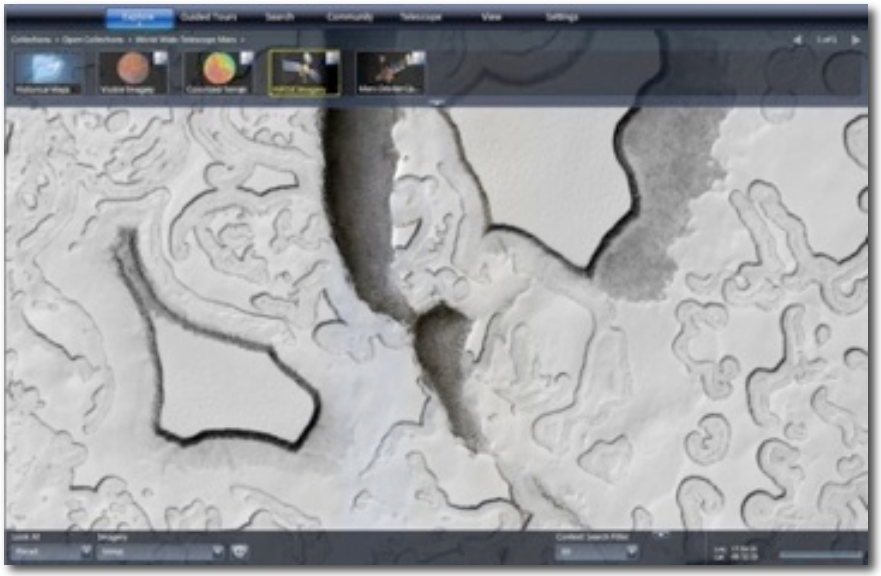
WorldWide Telescope: Mars

Explore Mars in 3D

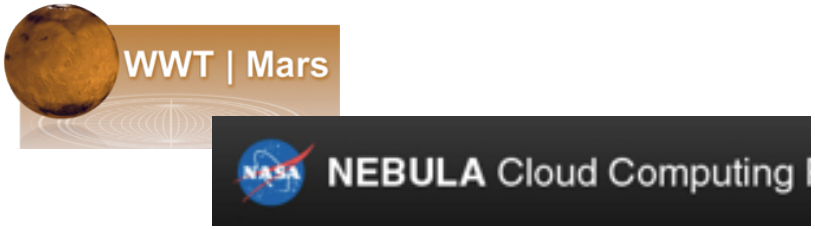
- Released July 12, 2010
- Co-developed with Microsoft Research
- http://worldwidetelescope.org

Content

- Largest digital image mosaic of Mars ever created
- Historical maps
- Guided tours (Carol Stoker and Jim Garvin)



		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**



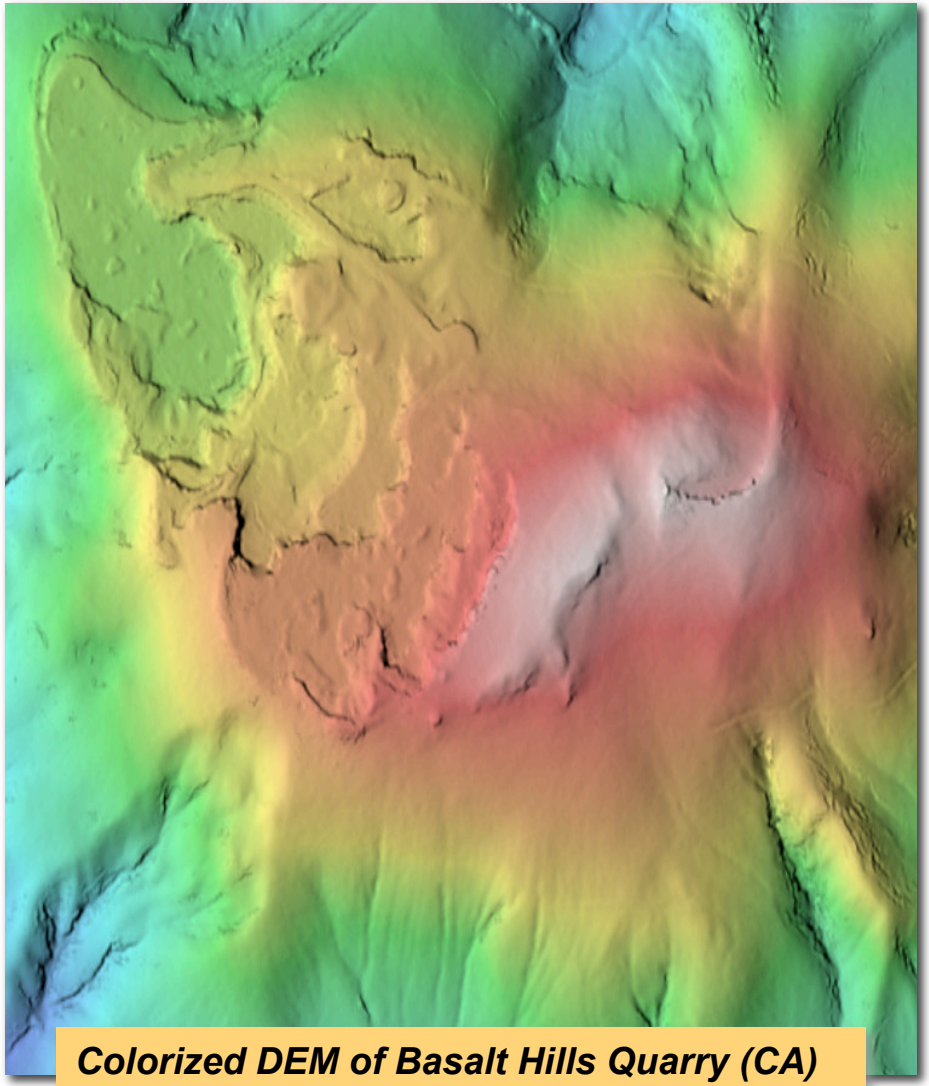
Ames Stereo Pipeline (ASP) for Earth

ASP for Earth (open-source)

- High-quality stereo correlation for large satellite images
- Camera models for NASA satellites, DigitalGlobe satellites, RPC imagers, etc.
- Linux/OS-X command-line tools (desktop to super computers)

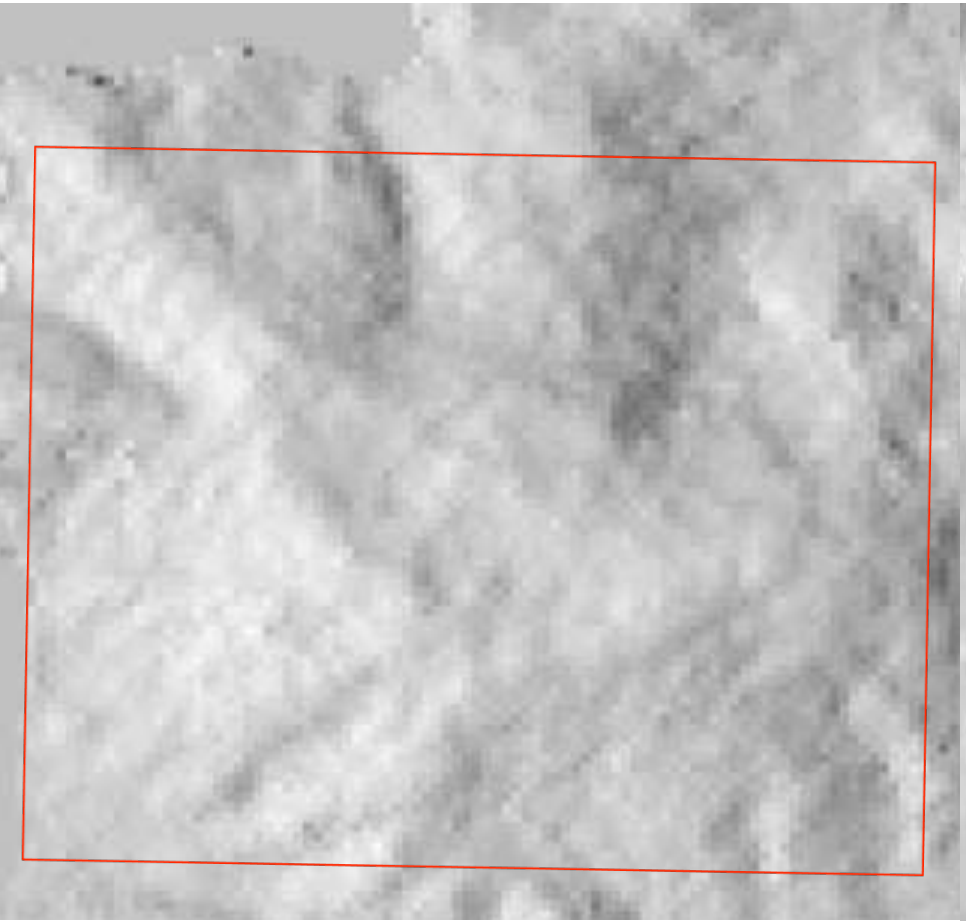
Performance

- Approx. 5 min CPU time / km^2 (NASA Pleiades supercomputer with 3 GHz Xeon processors)
- 5 hours for DigitalGlobe stereo imagery subsampled to 1 m/px
- 60% success rate without any human intervention

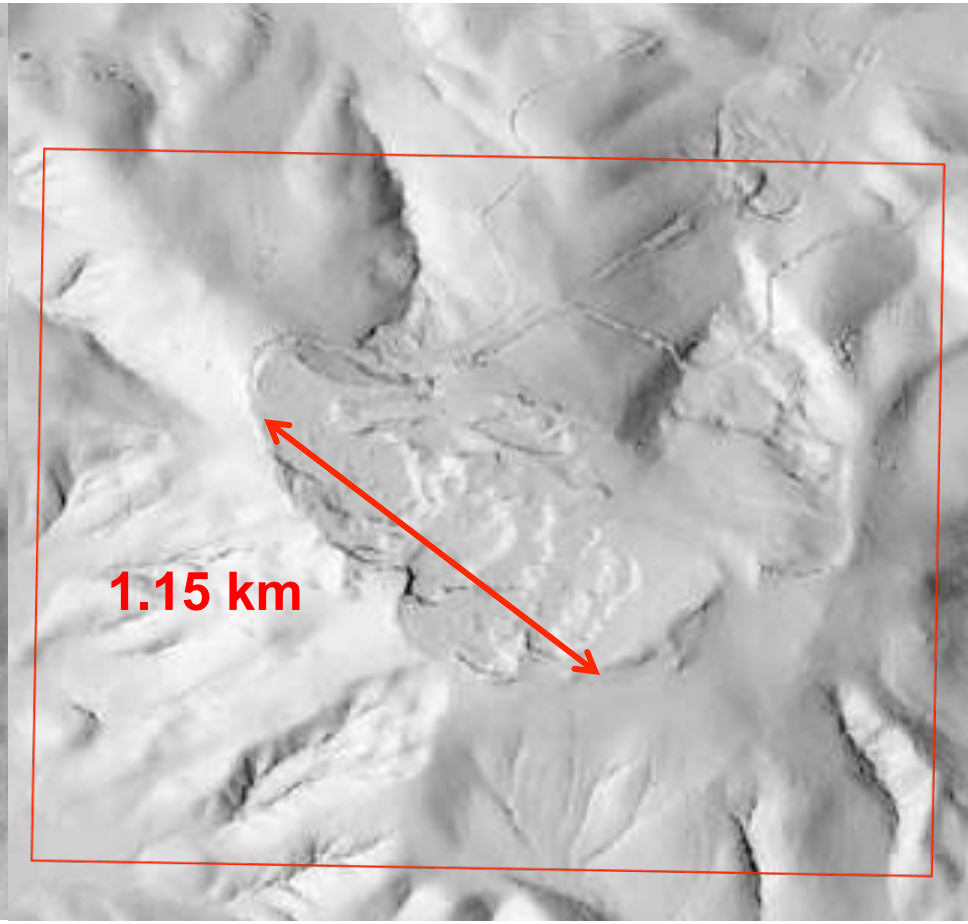


Colorized DEM of Basalt Hills Quarry (CA) derived from Digital Globe WorldView

SRTM vs. Ames Stereo Pipeline

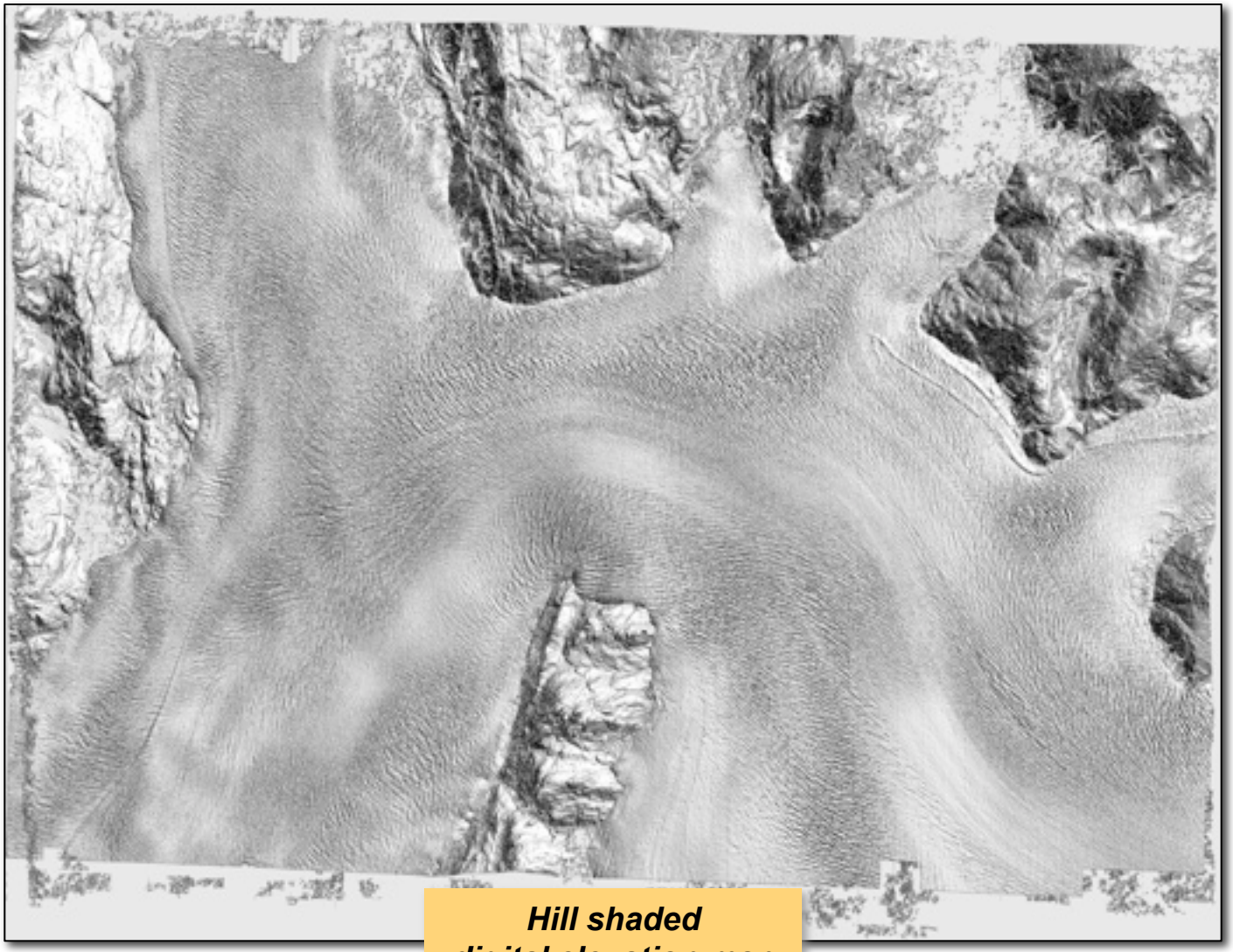


Shuttle Radar Topography Mission (30 m/pixel)



Ames Stereo Pipeline (DG WorldView, 1.5 m/pixel)

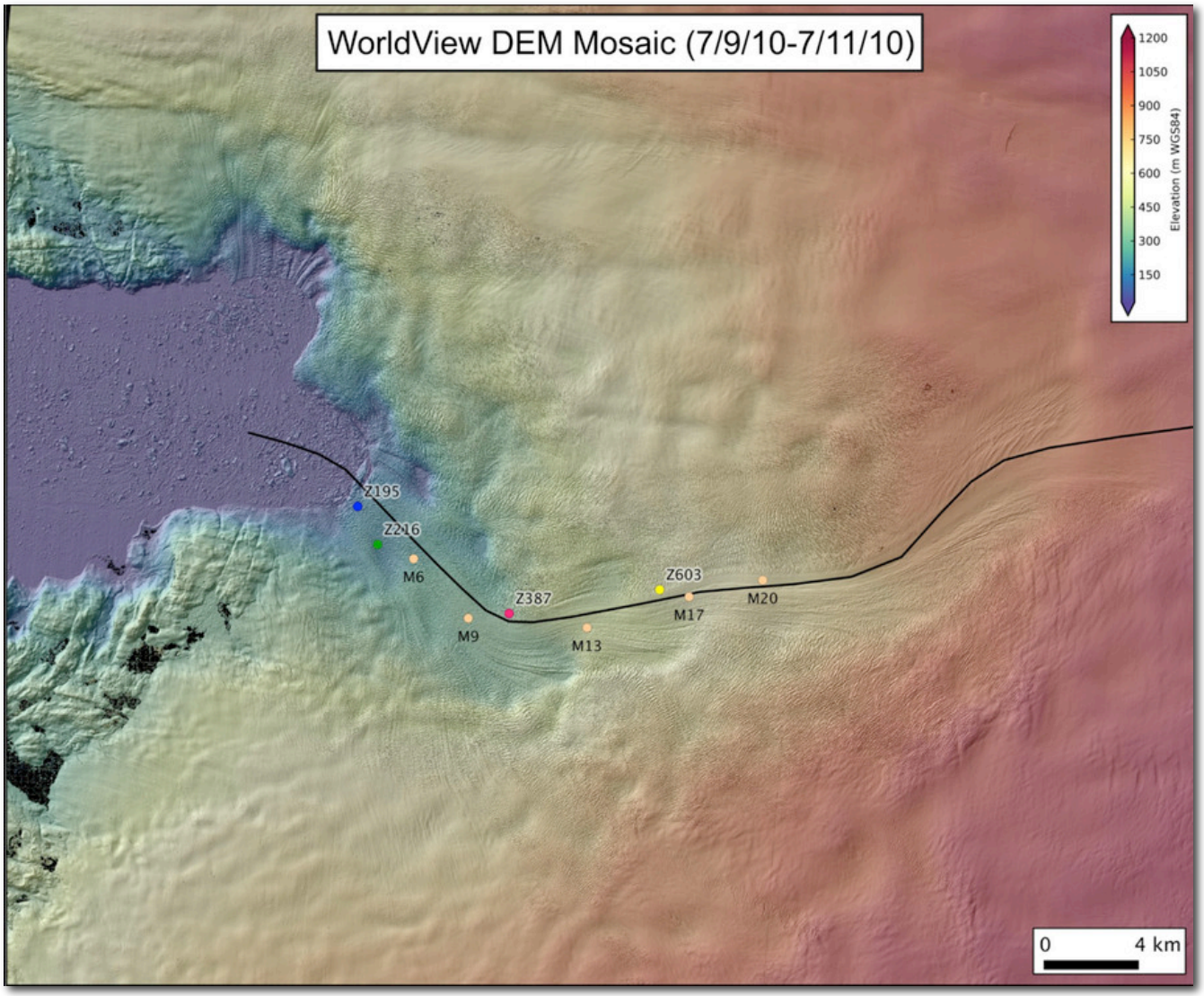
South American Glacier



Hill shaded digital elevation map

Credit: M. WIllis

Jakobshavn Glacier



3-5 m/pixel
2,500 km²
(6 input images)

Credit: D. Shean
(Univ. of Wash)

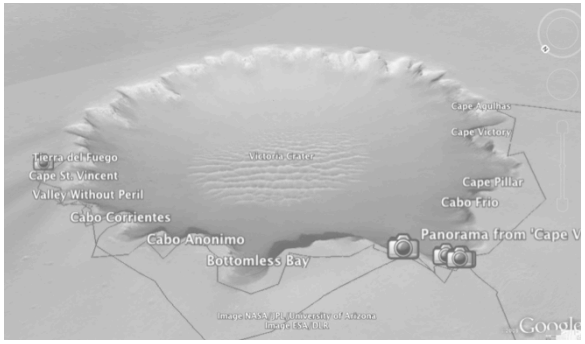
New Ways of Exploring

Part 1: Robots for human exploration

- Complement & supplement humans
- Off-load “unproductive” tasks
- Before, supporting, & after humans

Part 2: Neo-geography

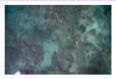
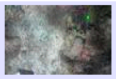
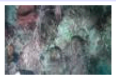
- Automated planetary mapping
- Easy access to planetary data
- “Desktop exploration”



Part 3: Exploration GDS

- Reusable software tools for distributed science operations
- Web-based & open standards
- Plan, monitor, explore

Science Mission Support

Label	Note	Still	Video
sponge	area of barrel sponges		Full Video Compressed Video
sponge	space sponges		Full Video Compressed Video
other	completed first pass		Full Video Compressed Video
other	going in reverse		Full Video Compressed Video
other	start moving to waypoint		Full Video Compressed Video

Plan

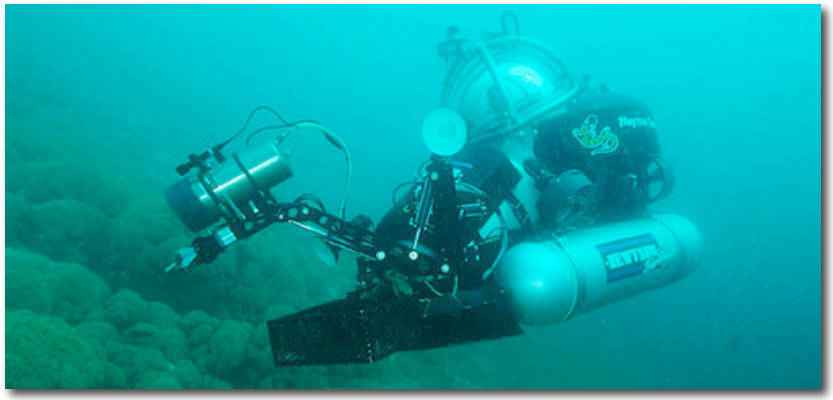
Monitor

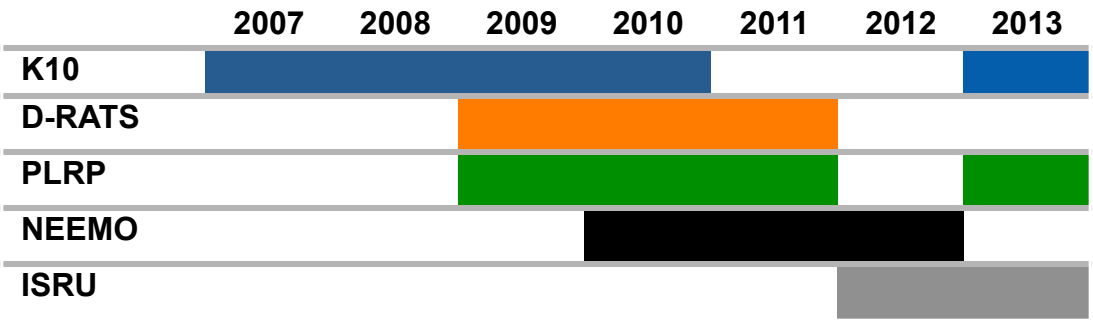
Explore

BEFORE ***DURING*** ***AFTER***

Exploration Use Cases





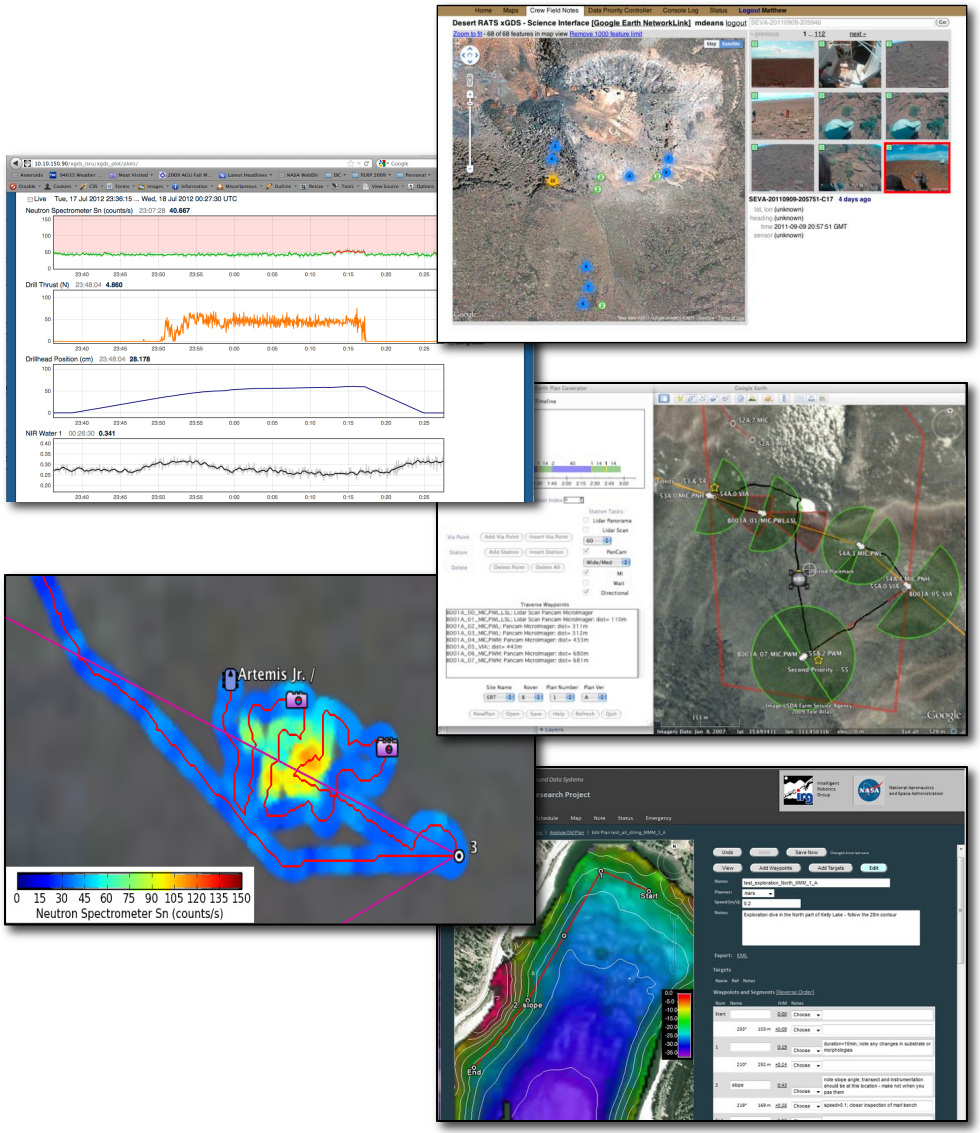
Exploration Ground Data System (xGDS)

xGDS is …

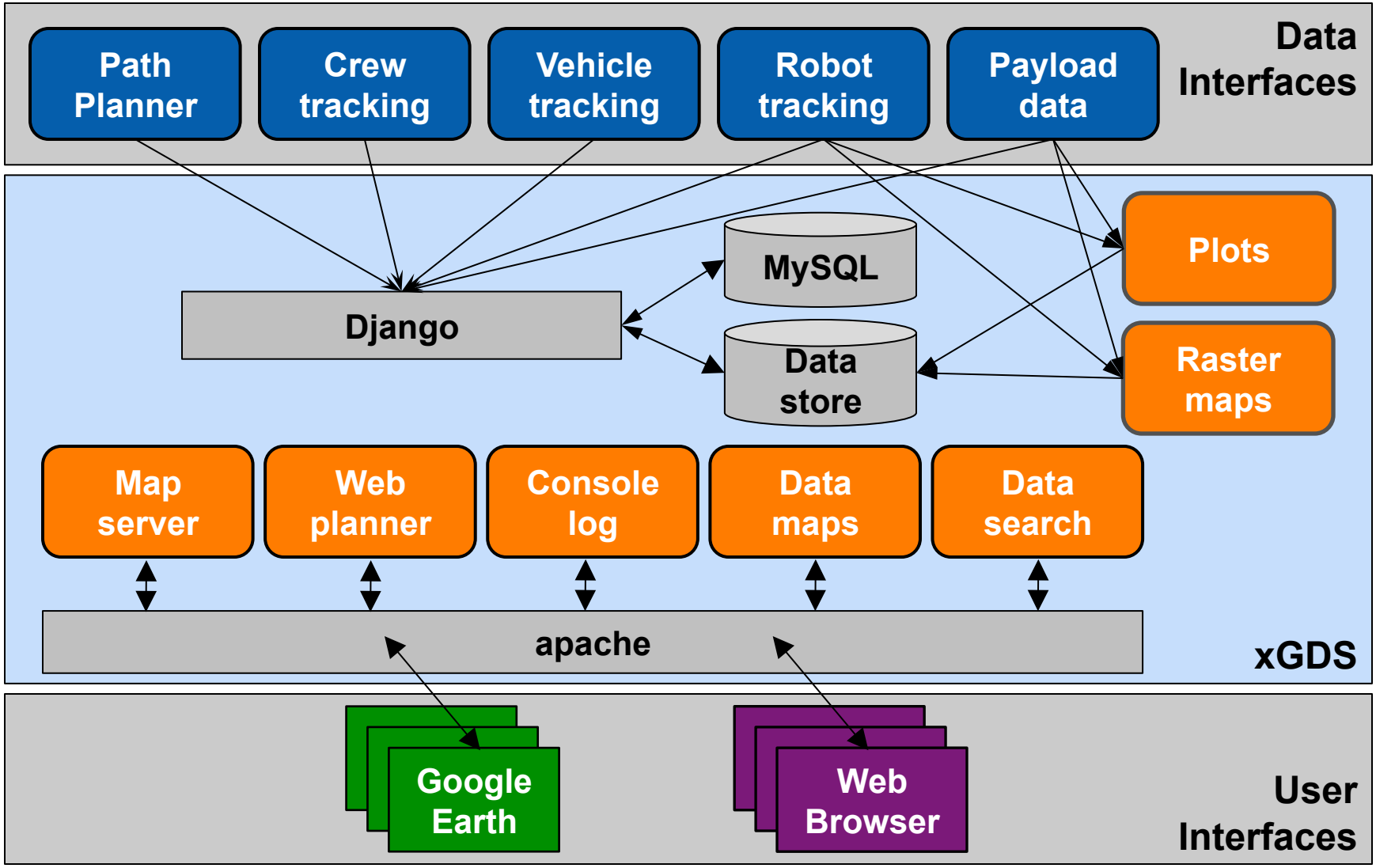
- Map content management
- Planning tool
- Real-time plots, maps, notes
- Post-processing data archive
- Browse and search tools

Users

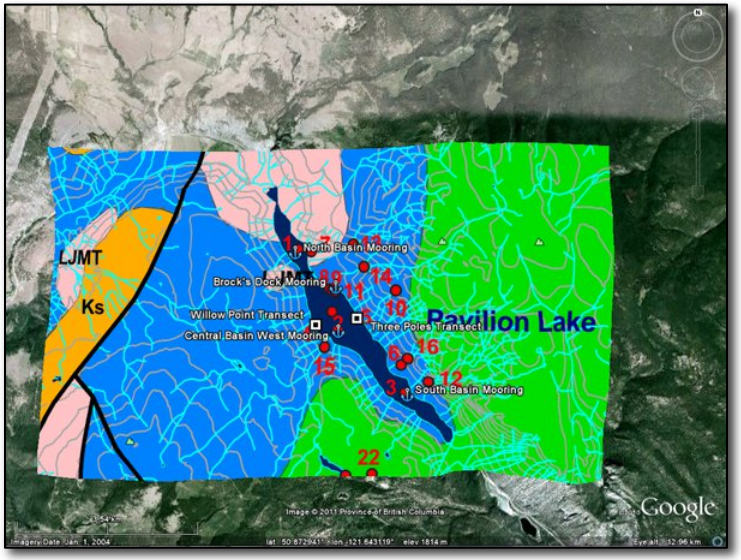
- Field scientists
- Planetary scientists
- Mission planners
- Flight controllers
- Local & distributed teams

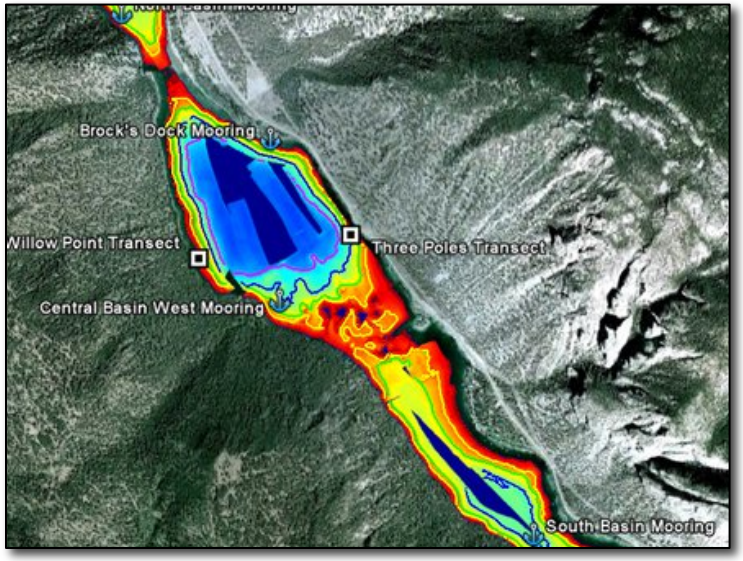


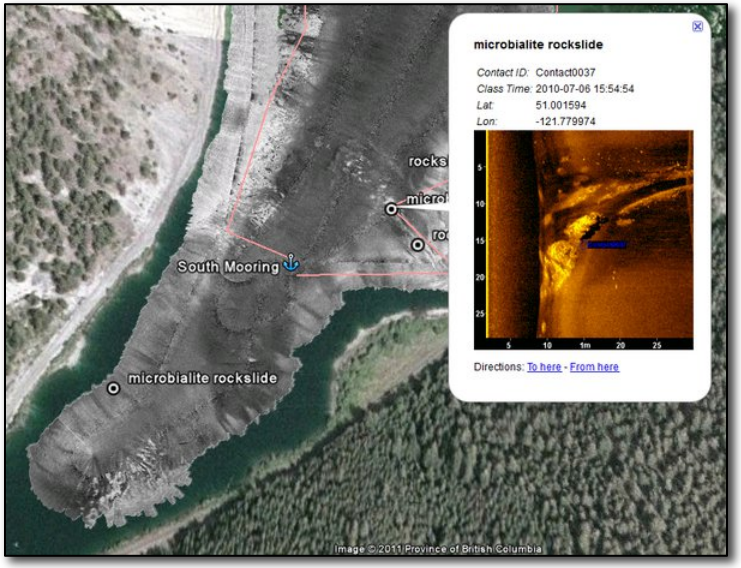
Architecture

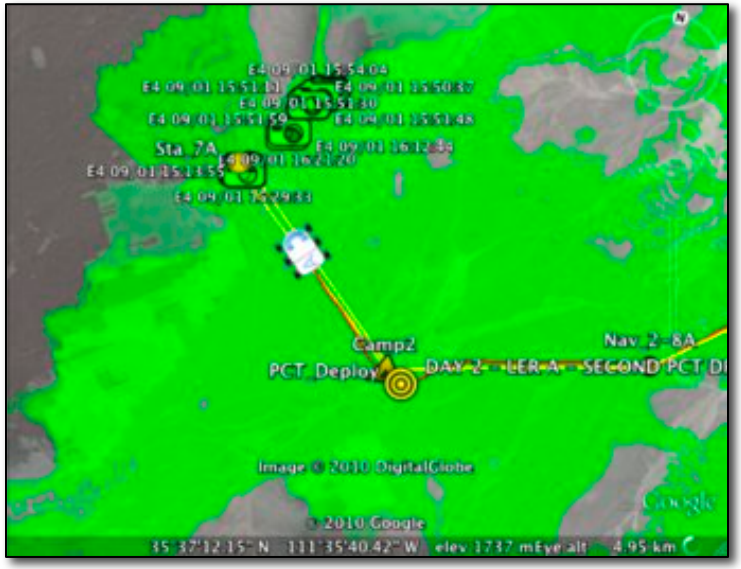


Map Server

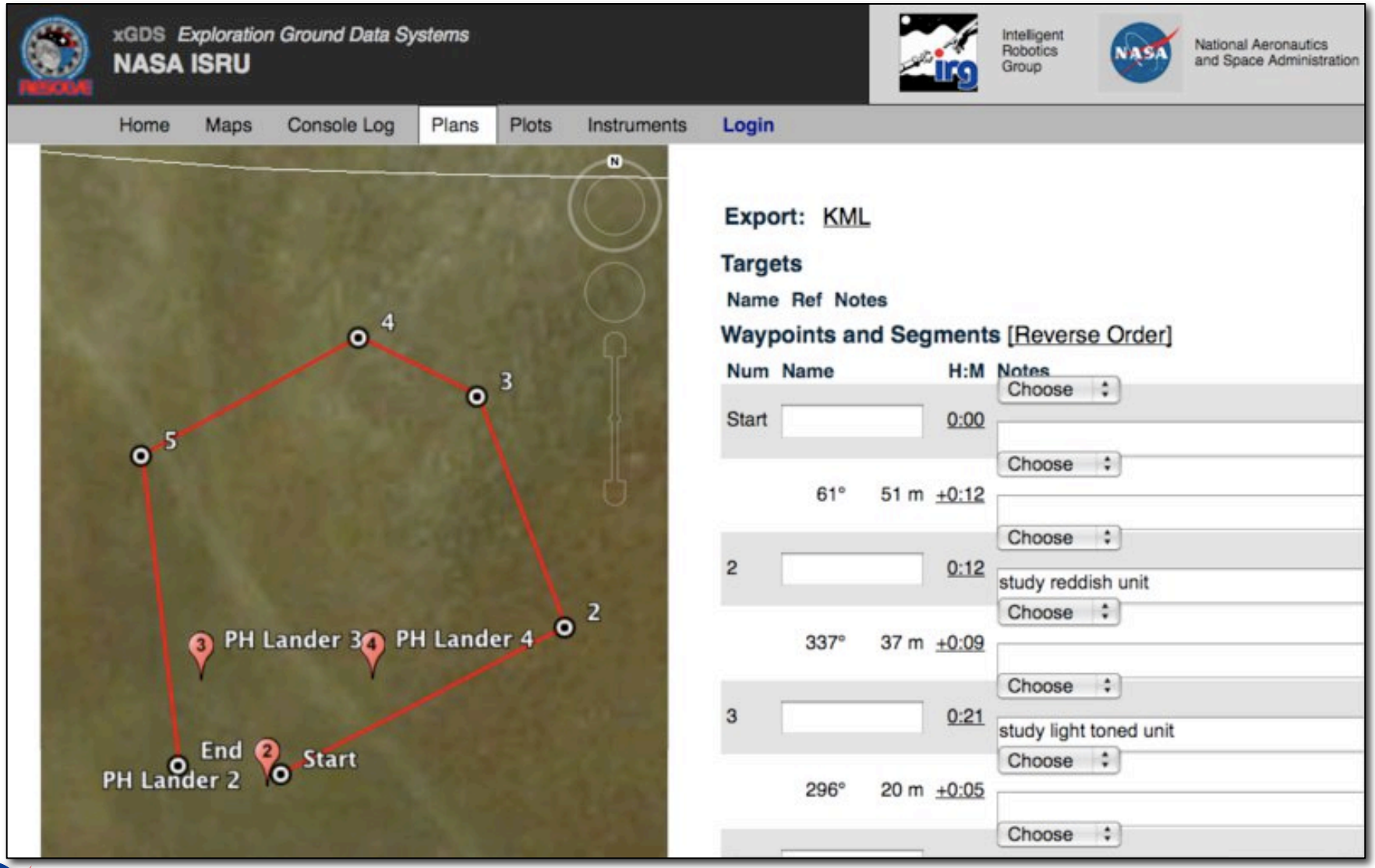

LJMT
Ks
North Basin Mooring
Brock's Dock Mooring
Willow Point Transect
Central Basin West Mooring
Three Poles Transect
Pavilion Lake
South Basin Mooring
Google


Brock's Dock Mooring
Willow Point Transect
Three Poles Transect
Central Basin West Mooring
South Basin Mooring

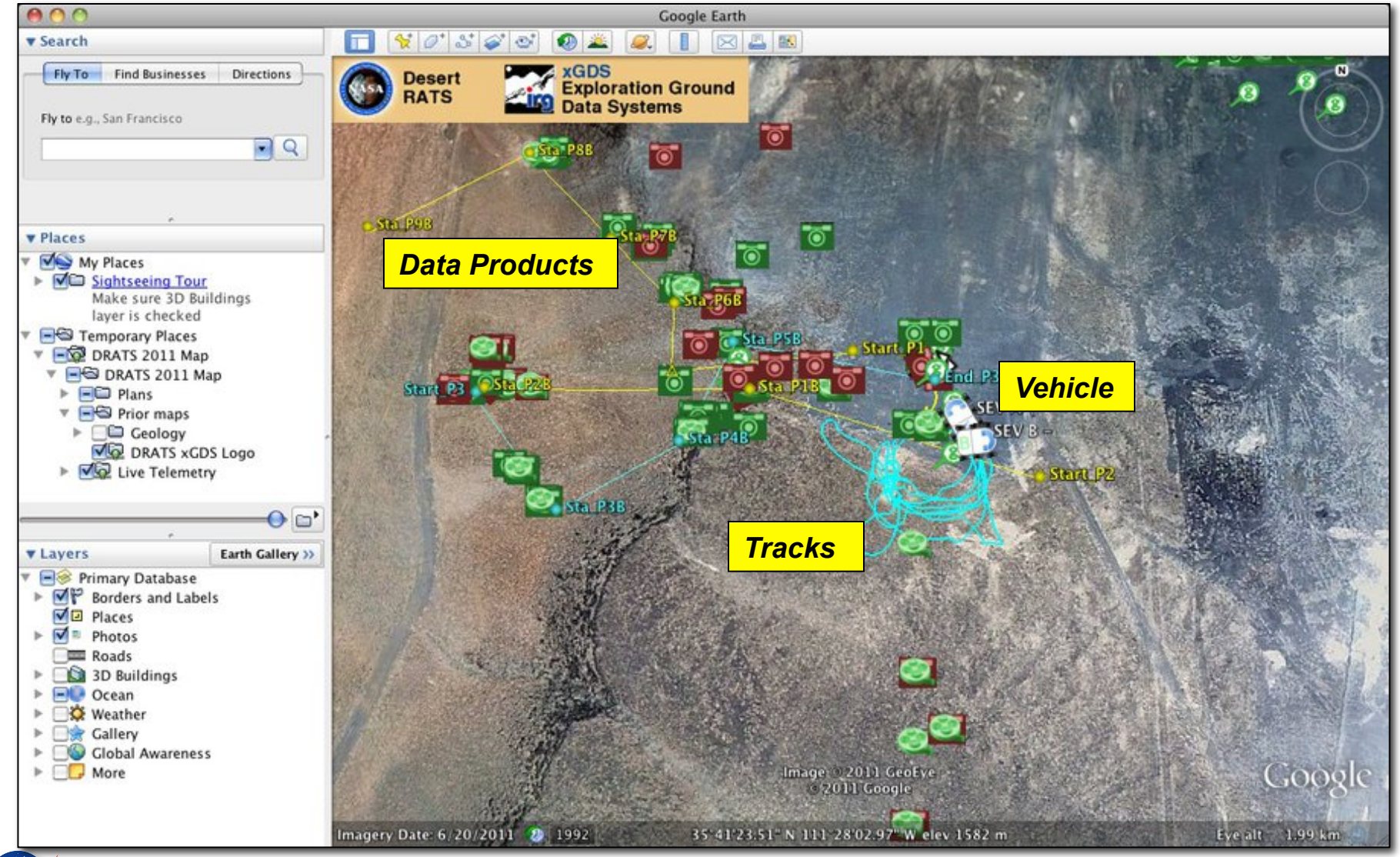

microbialite rockslide
Contact ID: Contact0037
Class Time: 2010-07-06 15:54:54
Lat: 51.001594
Lon: -121.779974
Directions: To here - From here
South Mooring
microbialite rockslide


Sta_7A
Camp2
PCT_Deploy
Nav 2-8A
DAY 2 - LER-A - SECOND PCT
Image © 2010 DigitalGlobe
© 2010 Google

Web Planner


xGDS Exploration Ground Data Systems
NASA ISRU
Intelligent Robotics Group
National Aeronautics and Space Administration
Home
Maps
Console Log
Plans
Plots
Instruments
Login
PH Lander 3
PH Lander 4
End
PH Lander 2
Start
Export: KML
Targets
Name Ref Notes
Waypoints and Segments [Reverse Order]
Num Name H:M Notes
Start 0:00
61° 51 m +0:12
2 0:12
study reddish unit
337° 37 m +0:09
3 0:21
study light toned unit
296° 20 m +0:05
Choose

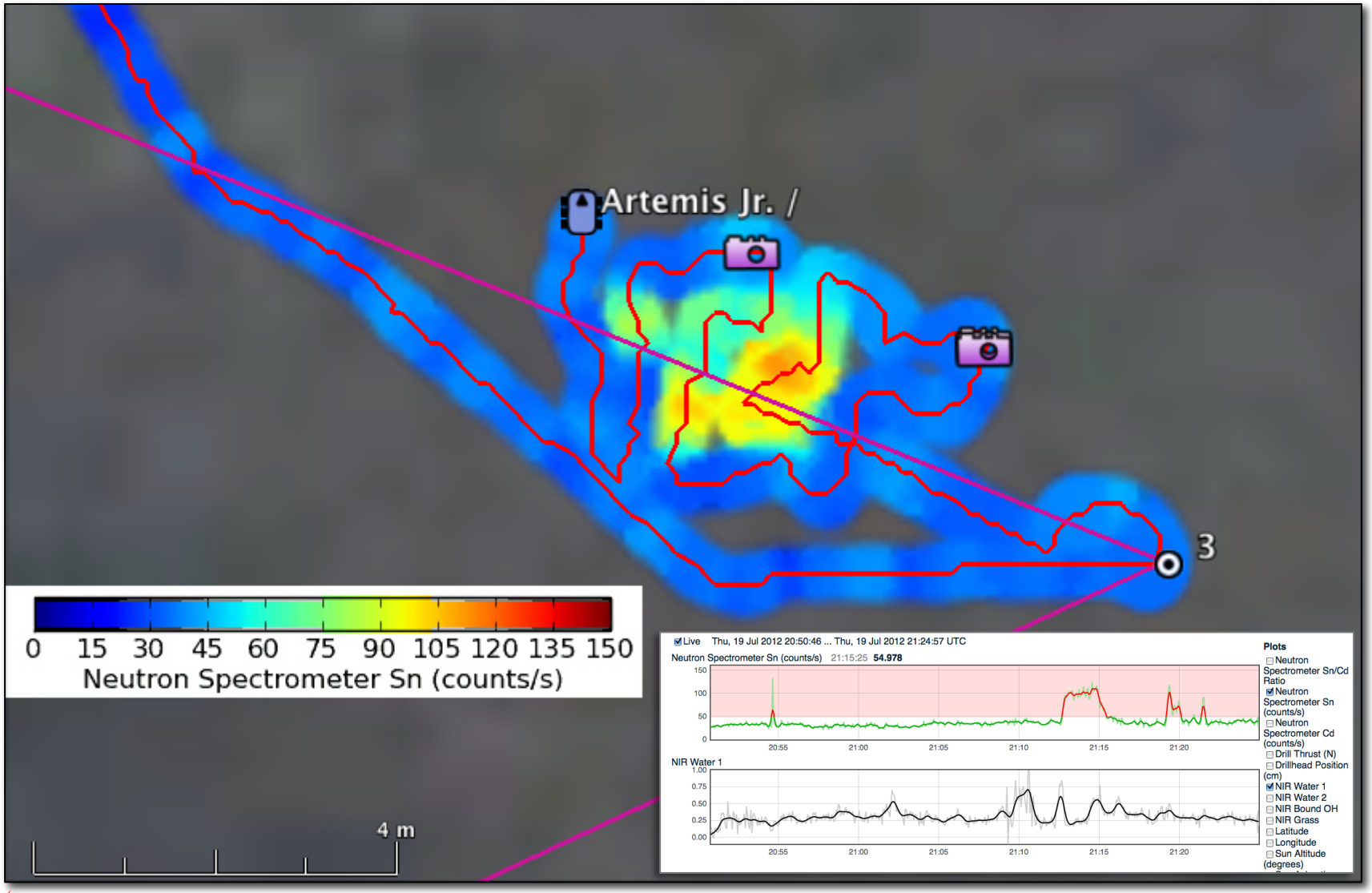
Tracking


Google Earth
Search
Fly To
Find Businesses
Directions
Fly to e.g., San Francisco
Places
My Places
Sightseeing Tour
Make sure 3D Buildings layer is checked
Temporary Places
DRATS 2011 Map
DRATS 2011 Map
Plans
Prior maps
Geology
DRATS xGDS Logo
Live Telemetry
Layers
Earth Gallery
Primary Database
Borders and Labels
Places
Photos
Roads
3D Buildings
Ocean
Weather
Gallery
Global Awareness
More
Desert RATS
xGDS Exploration Ground Data Systems
Data Products
Vehicle
Tracks
Sta_P8B
Sta_P9B
Sta_P7B
Sta_P6B
Sta_P5B
Sta_P1B
Sta_P2B
Sta_P3B
Sta_P4B
Start_P1
End_P3
Start_P3
Start_P2
SEV B
Image © 2011 GeoEye
© 2011 Google
Google
Imagery Date: 6/20/2011
1992
35°41'23.51" N 111°28'02.97" W elev 1582 m
Eye alt 1.99 km

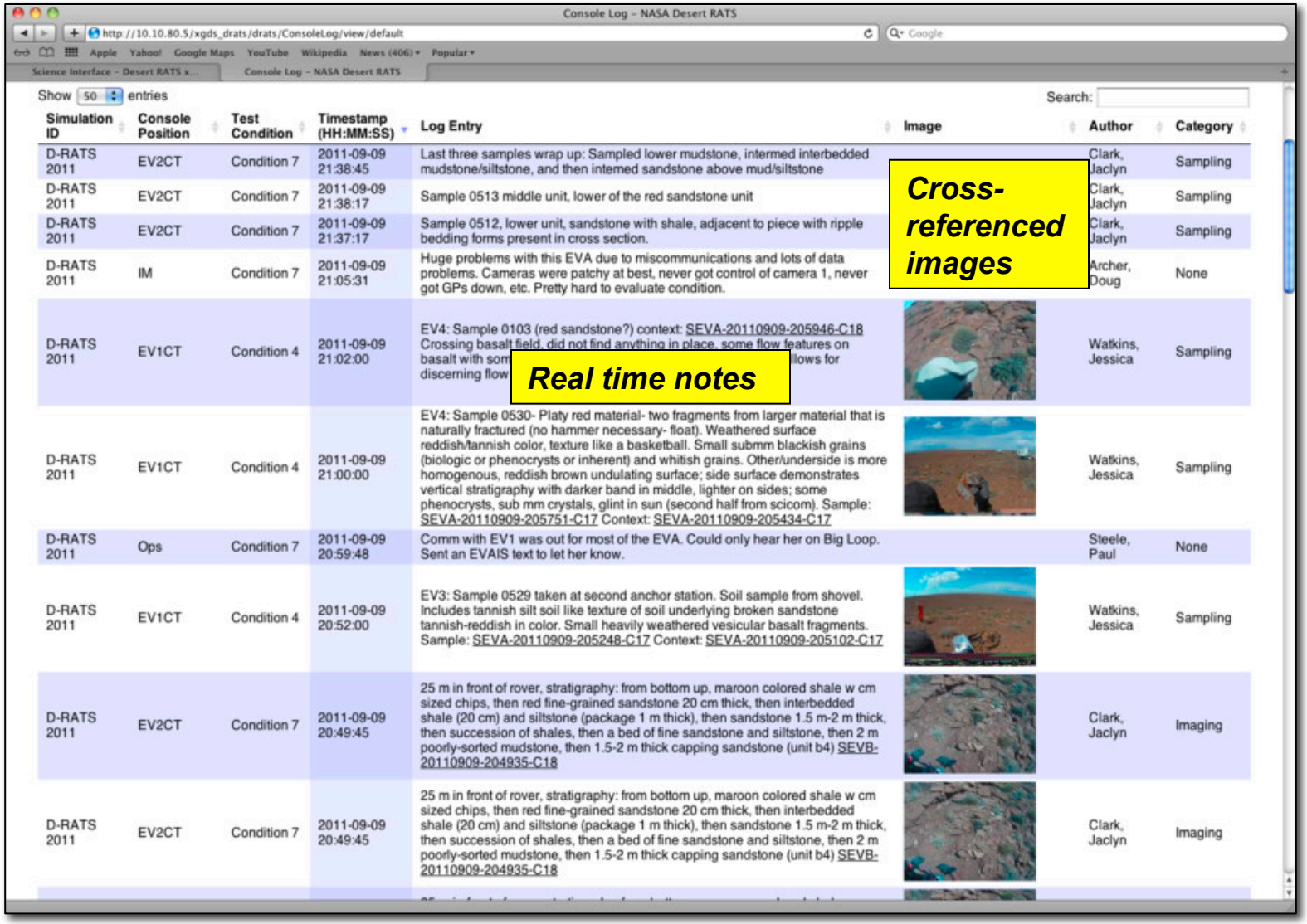
Plots


10.10.150.90/xgds_isru/xgds_plot/plots/
Live Tue, 17 Jul 2012 23:36:15 ... Wed, 18 Jul 2012 00:27:30 UTC
Neutron Spectrometer Sn (counts/s) 23:07:28 40.667
Drill Thrust (N) 23:48:04 4.860
Drillhead Position (cm) 23:48:04 28.178
NIR Water 1 00:26:30 0.341
23:40 23:45 23:50 23:55 0:00 0:05 0:10 0:15 0:20 0:25
Plots
Neutron Spectrometer Sn/Cd Ratio
Neutron Spectrometer Sn (counts/s)
Neutron Spectrometer Cd (counts/s)
Drill Thrust (N)
Drillhead Position (cm)
NIR Water 1
NIR Water 2
NIR Bound OH
NIR Grass
Latitude
Longitude

Raster Maps

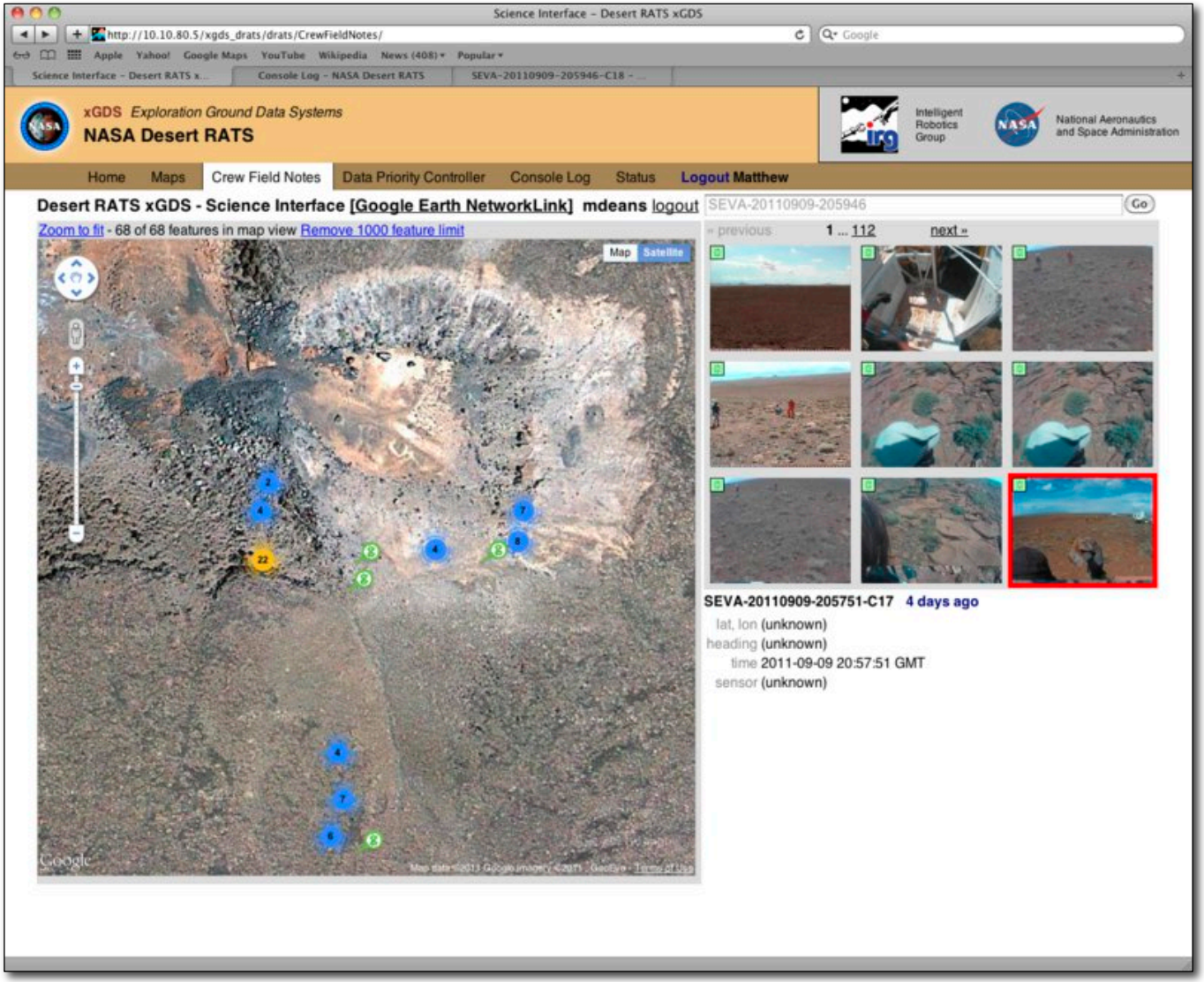

Artemis Jr. /
3
0 15 30 45 60 75 90 105 120 135 150
Neutron Spectrometer Sn (counts/s)
4 m
Live Thu, 19 Jul 2012 20:50:46 ... Thu, 19 Jul 2012 21:24:57 UTC
Neutron Spectrometer Sn (counts/s) 21:15:25 54.978
NIR Water 1
Plots
Neutron Spectrometer Sn/Cd Ratio
Neutron Spectrometer Sn (counts/s)
Neutron Spectrometer Cd (counts/s)
Drill Thrust (N)
Drillhead Position (cm)
NIR Water 1
NIR Water 2
NIR Bound OH
NIR Grass
Latitude
Longitude
Sun Altitude (degrees)

Console Log



Simulation ID	Console Position	Test Condition	Timestamp (HH:MM:SS)	Log Entry	Image	Author	Category
D-RATS 2011	EV2CT	Condition 7	2011-09-09 21:38:45	Last three samples wrap up: Sampled lower mudstone, intermed interbedded mudstone/siltstone, and then intemed sandstone above mud/siltstone		Clark, Jaclyn	Sampling
D-RATS 2011	EV2CT	Condition 7	2011-09-09 21:38:17	Sample 0513 middle unit, lower of the red sandstone unit		Clark, Jaclyn	Sampling
D-RATS 2011	EV2CT	Condition 7	2011-09-09 21:37:17	Sample 0512, lower unit, sandstone with shale, adjacent to piece with ripple bedding forms present in cross section.		Clark, Jaclyn	Sampling
D-RATS 2011	IM	Condition 7	2011-09-09 21:05:31	Huge problems with this EVA due to miscommunications and lots of data problems. Cameras were patchy at best, never got control of camera 1, never got GPs down, etc. Pretty hard to evaluate condition.		Archer, Doug	None
D-RATS 2011	EV1CT	Condition 4	2011-09-09 21:02:00	EV4: Sample 0103 (red sandstone?) context: SEVA-20110909-205946-C18 Crossing basalt field, did not find anything in place, some flow features on basalt with som… lows for discerning flow		Watkins, Jessica	Sampling
D-RATS 2011	EV1CT	Condition 4	2011-09-09 21:00:00	EV4: Sample 0530- Platy red material- two fragments from larger material that is naturally fractured (no hammer necessary- float). Weathered surface reddish/tannish color, texture like a basketball. Small submm blackish grains (biologic or phenocrysts or inherent) and whitish grains. Other/underside is more homogenous, reddish brown undulating surface; side surface demonstrates vertical stratigraphy with darker band in middle, lighter on sides; some phenocrysts, sub mm crystals, glint in sun (second half from scicom). Sample: SEVA-20110909-205751-C17 Context: SEVA-20110909-205434-C17		Watkins, Jessica	Sampling
D-RATS 2011	Ops	Condition 7	2011-09-09 20:59:48	Comm with EV1 was out for most of the EVA. Could only hear her on Big Loop. Sent an EVAIS text to let her know.		Steele, Paul	None
D-RATS 2011	EV1CT	Condition 4	2011-09-09 20:52:00	EV3: Sample 0529 taken at second anchor station. Soil sample from shovel. Includes tannish silt soil like texture of soil underlying broken sandstone tannish-reddish in color. Small heavily weathered vesicular basalt fragments. Sample: SEVA-20110909-205248-C17 Context: SEVA-20110909-205102-C17		Watkins, Jessica	Sampling
D-RATS 2011	EV2CT	Condition 7	2011-09-09 20:49:45	25 m in front of rover, stratigraphy: from bottom up, maroon colored shale w cm sized chips, then red fine-grained sandstone 20 cm thick, then interbedded shale (20 cm) and siltstone (package 1 m thick), then sandstone 1.5 m-2 m thick, then succession of shales, then a bed of fine sandstone and siltstone, then 2 m poorly-sorted mudstone, then 1.5-2 m thick capping sandstone (unit b4) SEVB-20110909-204935-C18		Clark, Jaclyn	Imaging
D-RATS 2011	EV2CT	Condition 7	2011-09-09 20:49:45	25 m in front of rover, stratigraphy: from bottom up, maroon colored shale w cm sized chips, then red fine-grained sandstone 20 cm thick, then interbedded shale (20 cm) and siltstone (package 1 m thick), then sandstone 1.5 m-2 m thick, then succession of shales, then a bed of fine sandstone and siltstone, then 2 m poorly-sorted mudstone, then 1.5-2 m thick capping sandstone (unit b4) SEVB-20110909-204935-C18		Clark, Jaclyn	Imaging

Gallery


Science Interface – Desert RATS xGDS
http://10.10.80.5/xgds_drats/drats/CrewFieldNotes/
xGDS Exploration Ground Data Systems
NASA Desert RATS
Intelligent Robotics Group
National Aeronautics and Space Administration
Home
Maps
Crew Field Notes
Data Priority Controller
Console Log
Status
Logout Matthew
Desert RATS xGDS - Science Interface [Google Earth NetworkLink] mdeans logout
SEVA-20110909-205946
Go
Zoom to fit - 68 of 68 features in map view Remove 1000 feature limit
Map
Satellite
« previous
1 ... 112
next »
SEVA-20110909-205751-C17 4 days ago
lat, lon (unknown)
heading (unknown)
time 2011-09-09 20:57:51 GMT
sensor (unknown)

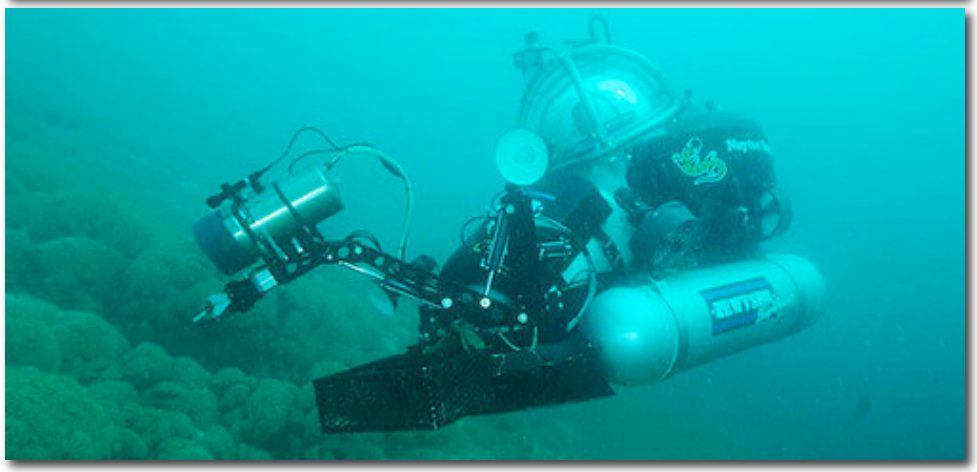
Pavillion Lake Research Project

Science objectives

- Map lake geology & biology
- Study microbialite formation

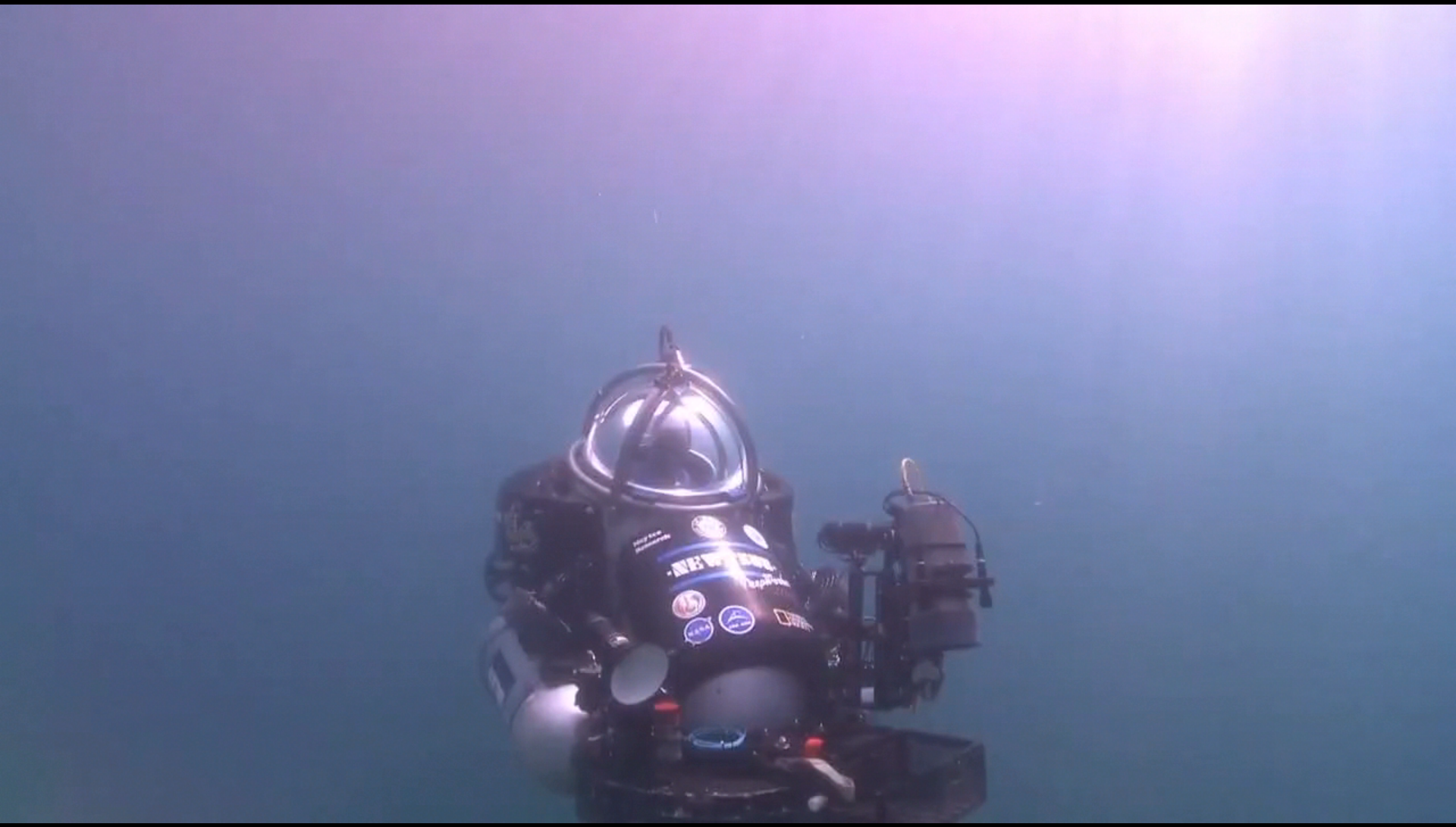
Challenges

- Distributed science team
  - Submersible pilot / scientist
  - Remote science team
- Real-time (re)planning
- Long-term data analysis

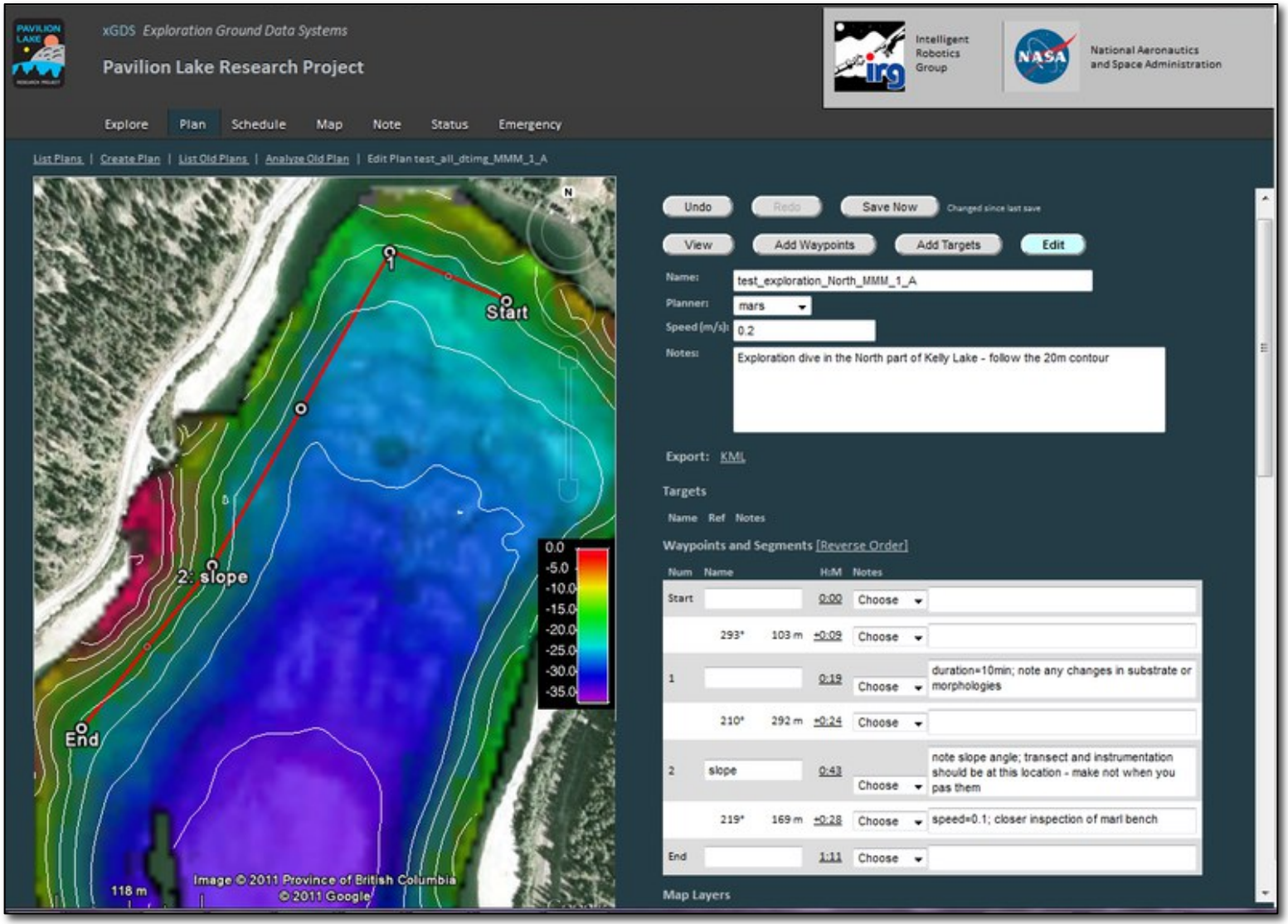


Planning needs

- Maps of the lake and surrounding area
- Data from past & precursor missions
- Where can we go & not go?
- Where do we need to start & end each flight?
- Coordination and collaboration



Web-based Planner

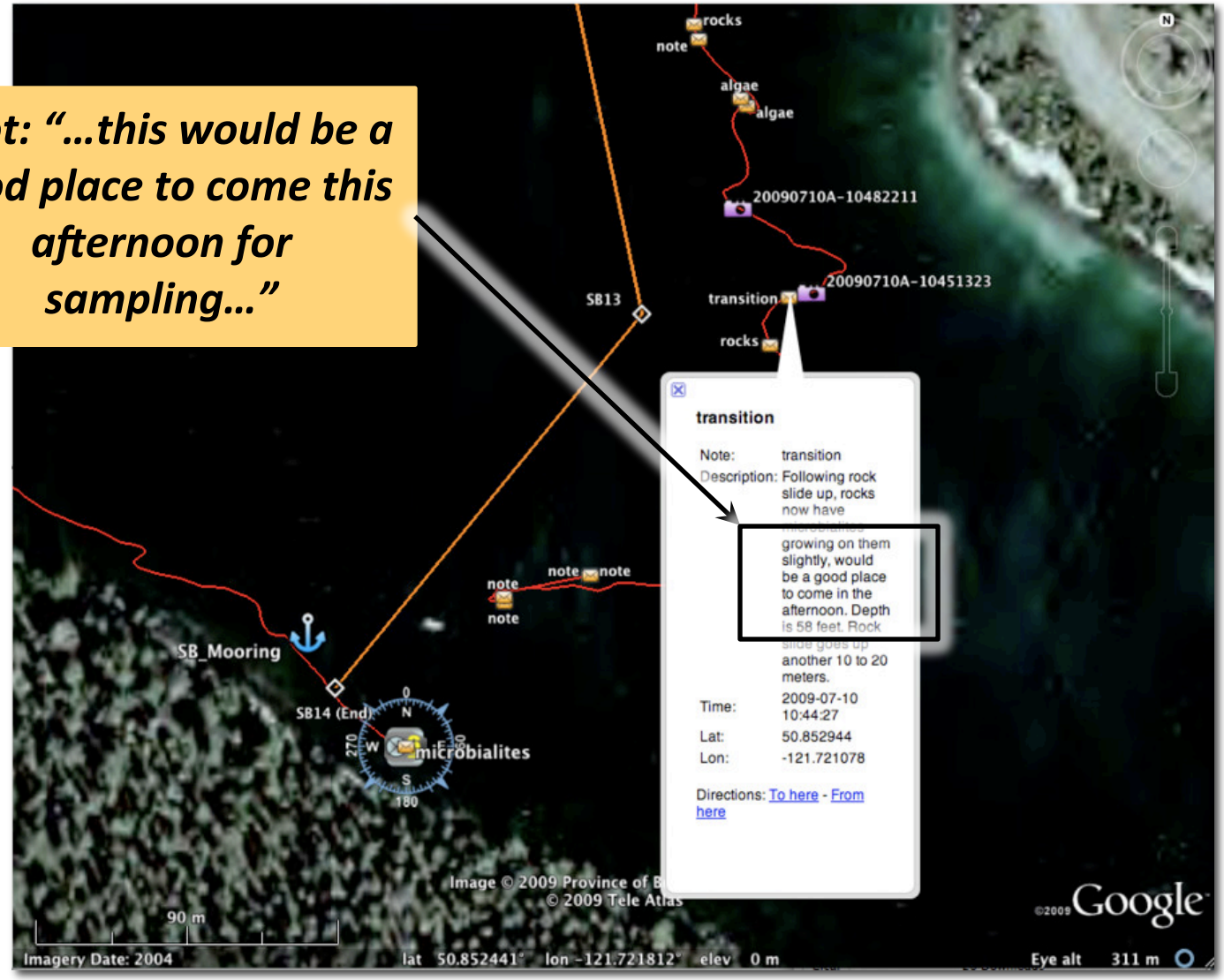


Monitoring

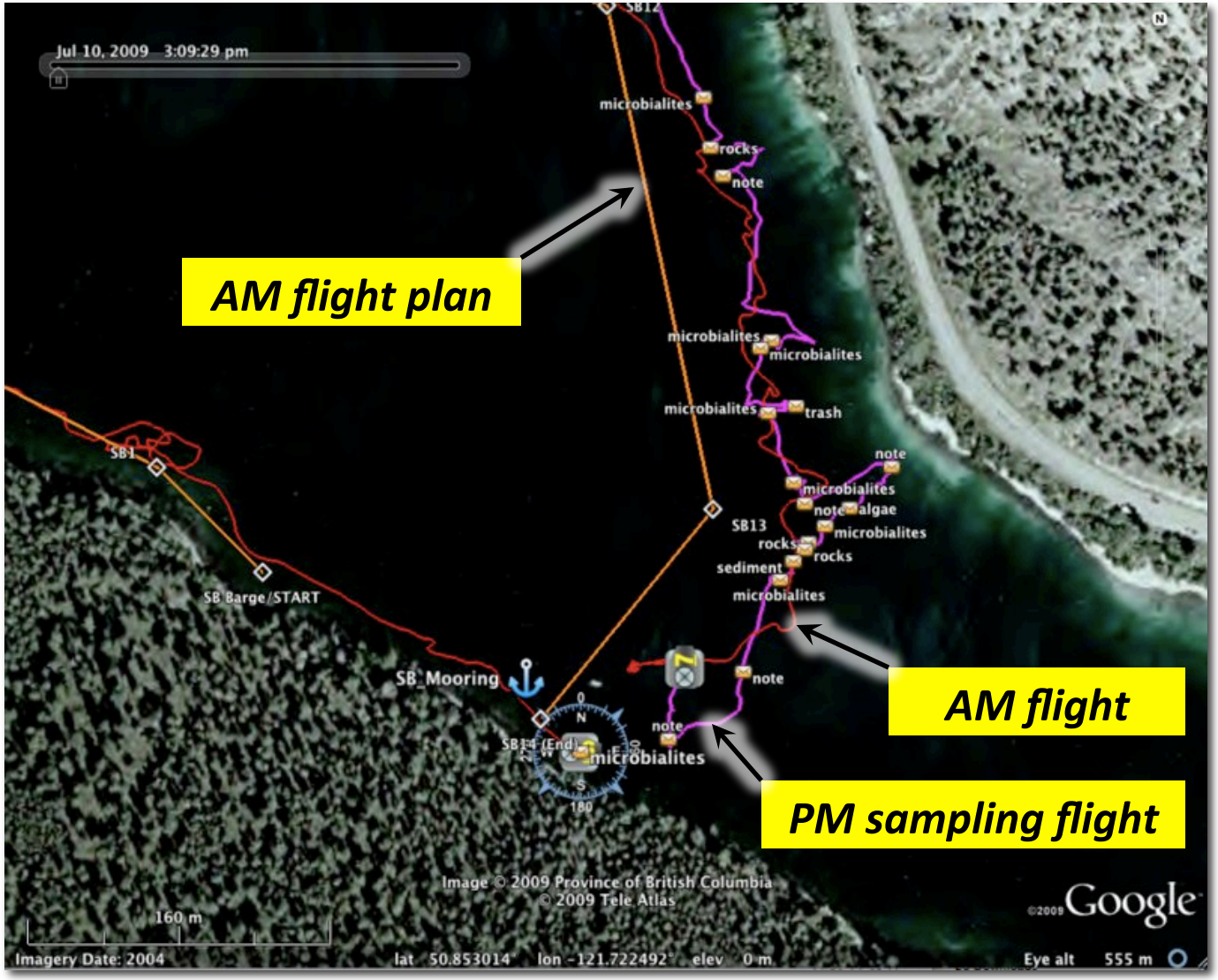

Vehicle
Notes
Tracks
Flight plan
End
Note
Note
Other
Algae
Algae
Microbialites
Microbialites
Rocks
Trees
Trees
Note
Algae
Kelly Lake
Image © 2011 Province of British Columbia
© 2011 Google
Google
191 m
Imagery Date: Dec 31, 2004 lat 51.006849° lon -121.777401° elev 1065 m Eye alt 1.80 km

Replanning

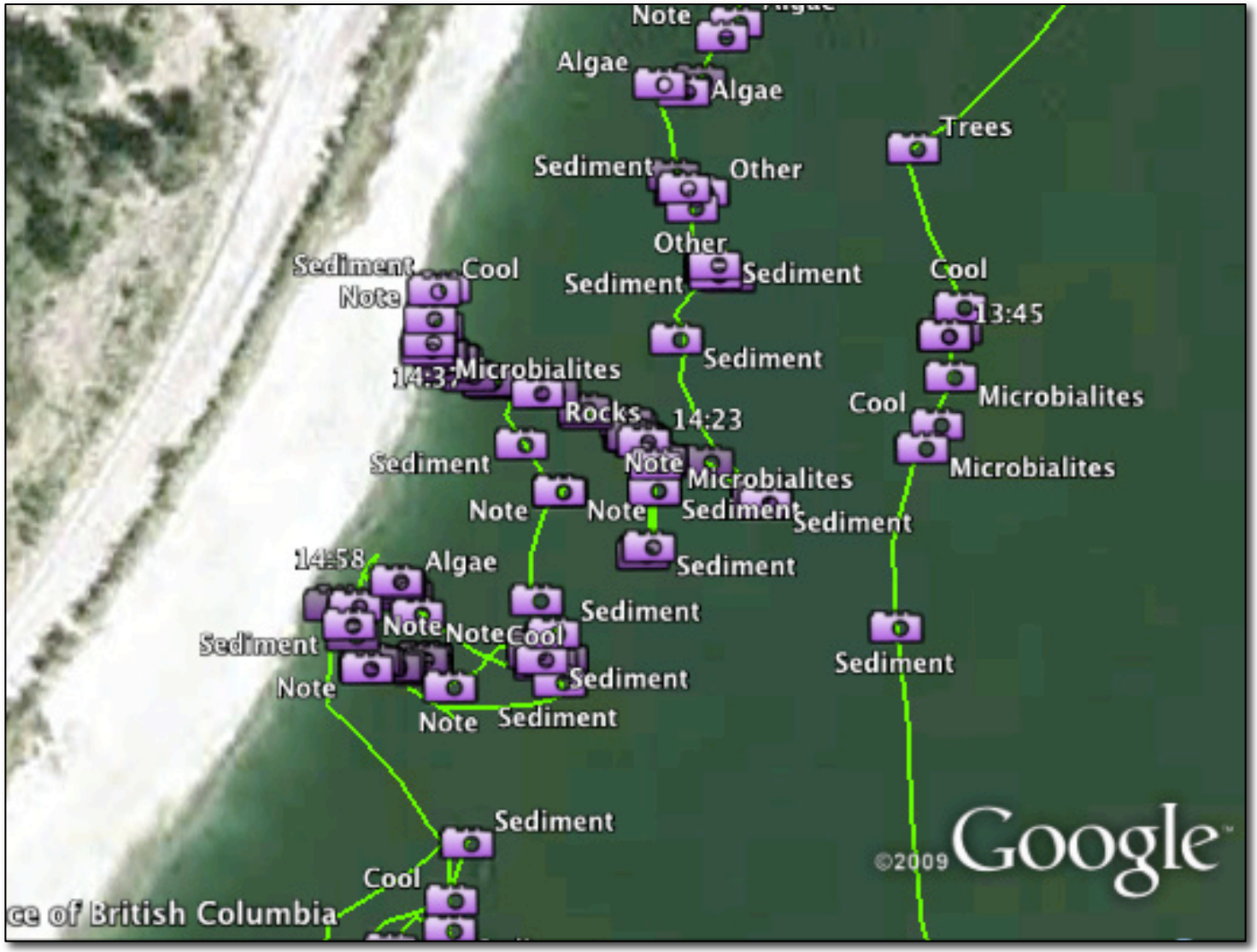
Pilot: "…this would be a good place to come this afternoon for sampling…"



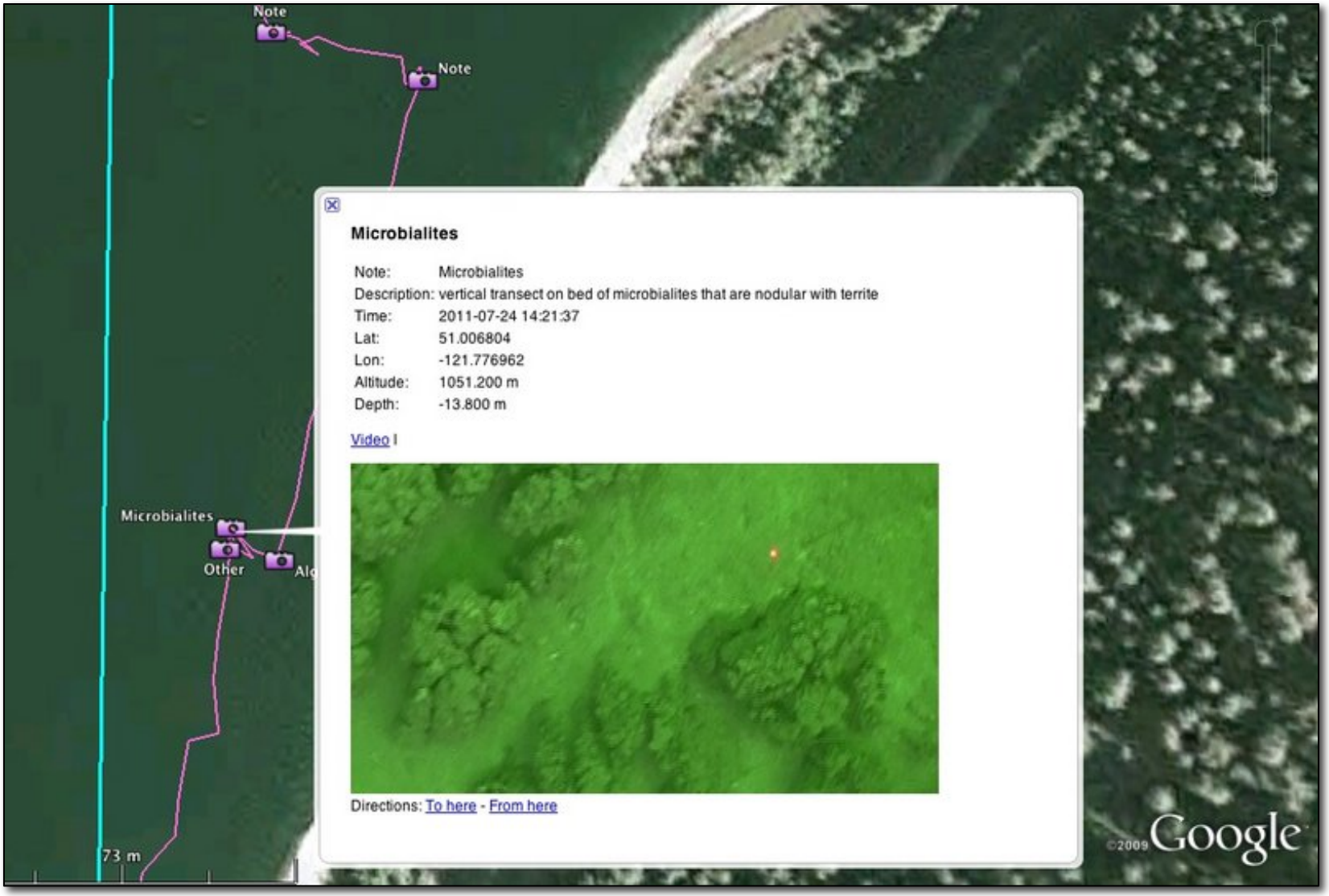
Map Display


Jul 10, 2009 3:09:29 pm
AM flight plan
AM flight
PM sampling flight
SB1
SB Barge/START
SB_Mooring
SB13
SB14 (End)
microbialites
rocks
note
trash
algae
sediment
Image © 2009 Province of British Columbia
© 2009 Tele Atlas
Google
160 m
Imagery Date: 2004
lat 50.853014° lon -121.722492° elev 0 m
Eye alt 555 m

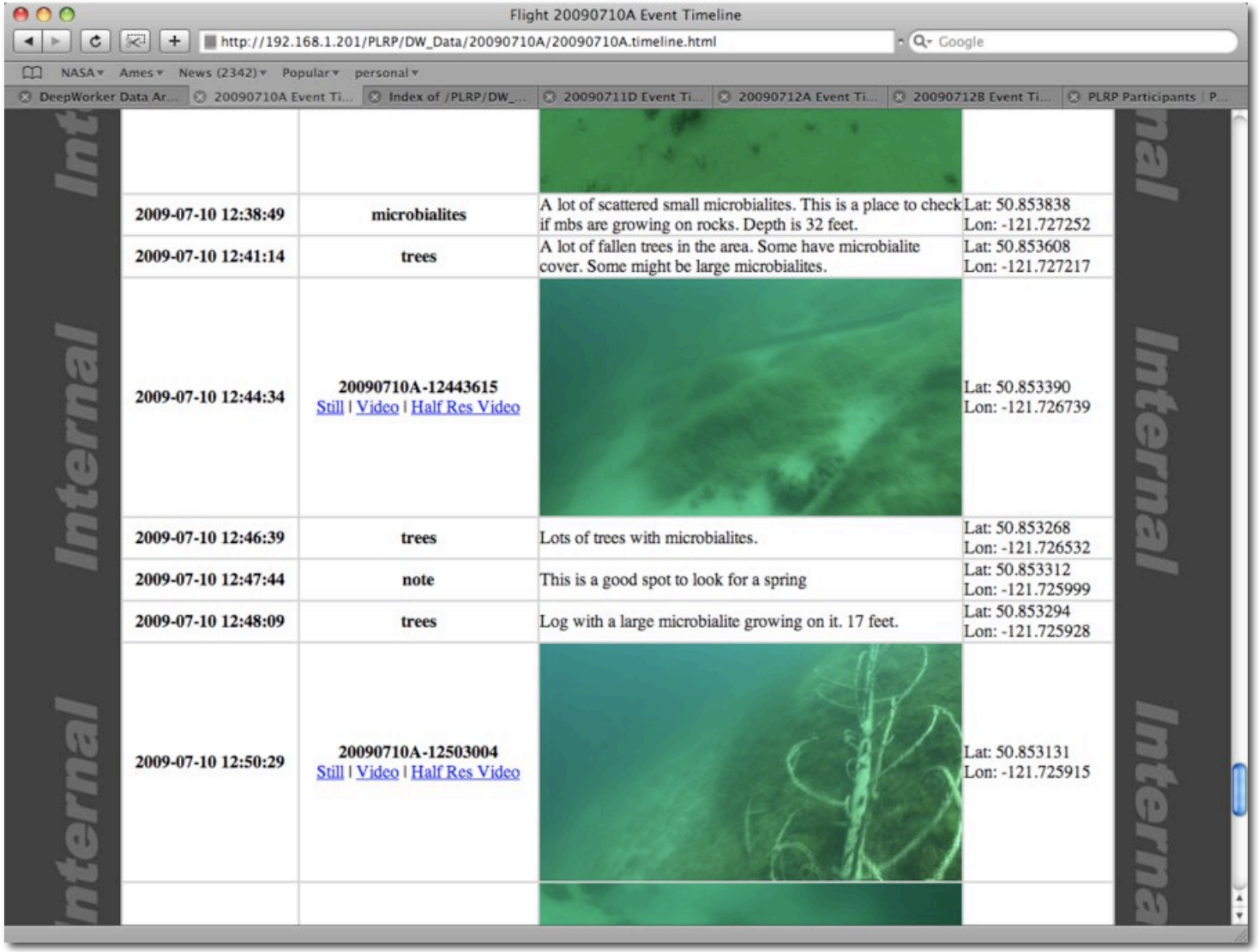
Data Browsing



Viewing Data



Timeline


Flight 20090710A Event Timeline
http://192.168.1.201/PLRP/DW_Data/20090710A/20090710A.timeline.html
Google
NASA
Ames
News (2342)
Popular
personal
DeepWorker Data Ar...
20090710A Event Ti...
Index of /PLRP/DW_...
20090711D Event Ti...
20090712A Event Ti...
20090712B Event Ti...
PLRP Participants
Internal
2009-07-10 12:38:49
microbialites
A lot of scattered small microbialites. This is a place to check if mbs are growing on rocks. Depth is 32 feet.
Lat: 50.853838
Lon: -121.727252
2009-07-10 12:41:14
trees
A lot of fallen trees in the area. Some have microbialite cover. Some might be large microbialites.
Lat: 50.853608
Lon: -121.727217
2009-07-10 12:44:34
20090710A-12443615
Still | Video | Half Res Video
Lat: 50.853390
Lon: -121.726739
2009-07-10 12:46:39
trees
Lots of trees with microbialites.
Lat: 50.853268
Lon: -121.726532
2009-07-10 12:47:44
note
This is a good spot to look for a spring
Lat: 50.853312
Lon: -121.725999
2009-07-10 12:48:09
trees
Log with a large microbialite growing on it. 17 feet.
Lat: 50.853294
Lon: -121.725928
2009-07-10 12:50:29
20090710A-12503004
Still | Video | Half Res Video
Lat: 50.853131
Lon: -121.725915

Development Lessons Learned

Open standards: HTML & KML

- Easy to create, distribute, and visualize content
  → **Focus on data, not on software**
- Google Earth, Firefox/Chrome/Safari
  → **Reduces development and training time**
- Facilitates integration with standards-compliant 3rd party tools

Modular implementation using open source

- Apache, MySQL, Django & Python, jQuery & JavaScript
- Focus on writing the “glue” between mature modules
- Quickly prototype new solutions/features

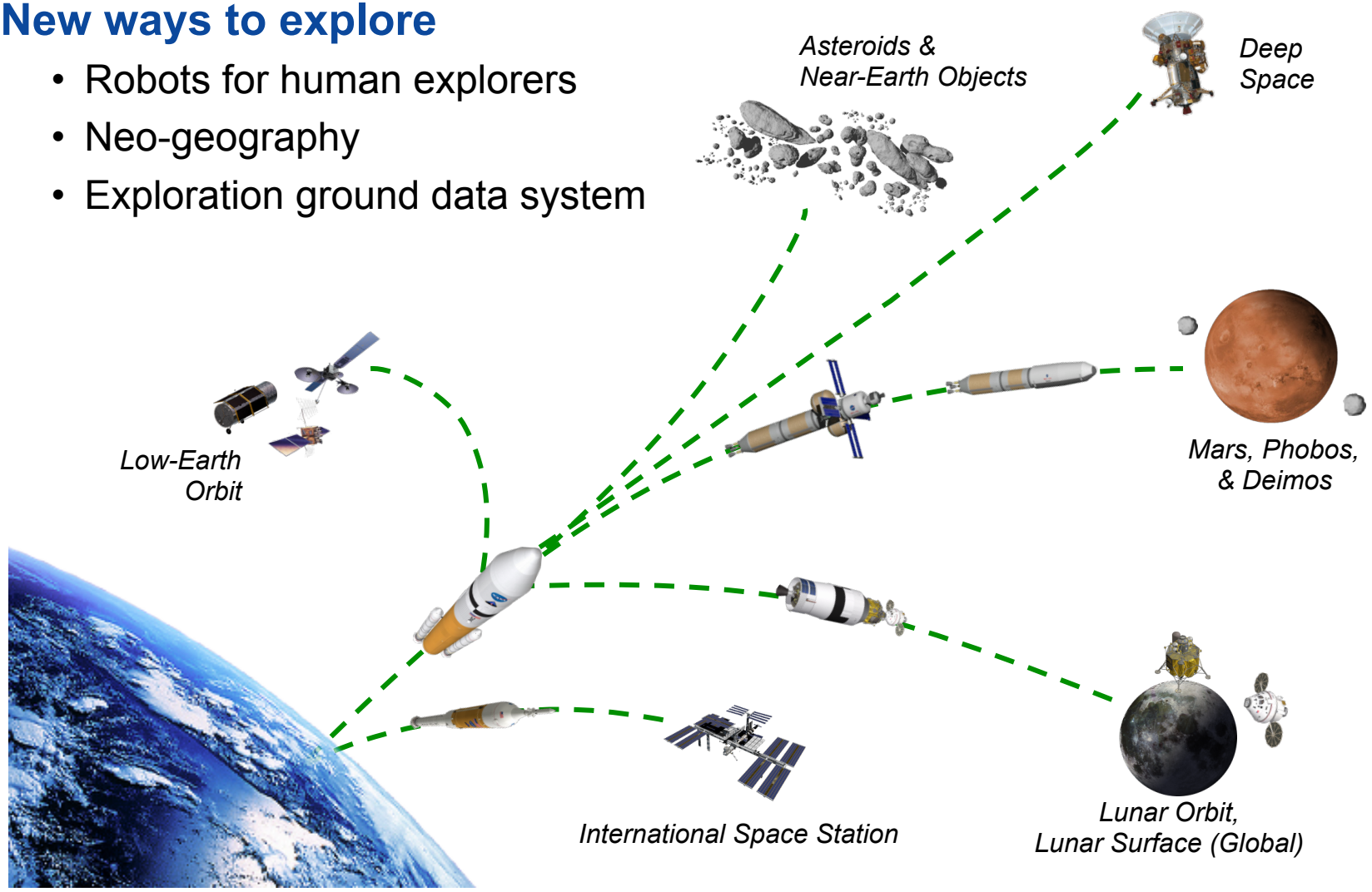
http://xgds.org

- Cloud hosting soon (Google AppEngine or Amazon EC2)
- Open-source release (Apache 2) this fall

Conclusion

New ways to explore

- Robots for human explorers
- Neo-geography
- Exploration ground data system



Questions?

Intelligent Robotics Group
Intelligent Systems Division
NASA Ames Research Center

irg.arc.nasa.gov