Introduction to RPIF-3D & 3D Imaging

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Stereo Panoramic Camera Science Team Member (ESA-Roscomos ExoMars20)

Overview

- **UCL & MSSL – who are we?**
- **Context :Planetary research at UCL**
- **RPIF-3D Facility**
- **UK RPIF News**
- **RPIF as a 3D Imaging Centre**
- **Tool & dataset development :**
  - **PRoViP for processing 3D rover imagery**
  - **PRoGIS for display and analysis of MER (and MSL in future) imaging data**
  - **PRo3D® for planetary science analysis of rover and spaceborne imagery**
  - **PRoViDE datasets**
  - **iMars datasets**

UCL Today

mostly

a vibrant academic community in the heart of London

- *Sunday Times University of the Year 2004*
- *In the top 4 UK universities, main competitors Oxford, Cambridge and Imperial College*
- *8 Faculties and 72 Departments*
- *12,400 academic, technical, admin and research staff*
- *37,000 students from 140 countries*
- *20 Nobel Prize winners (staff and alumni)*

- *its own theatre (the UCL Bloomsbury)*
- *its own museums and art collections*
- *the location for numerous films and TV programmes*

- *Campus in Qatar & Adelaide, South Australia*

UCL Provost & President
Prof Michael Arthur

Mullard Space Science Laboratory

advancing space science...

- located 50 km from UCL main campus in central London
- 22 km from Gatwick airport
- 40km from Heathrow airport
- members of department mainly focused on research and post-graduate supervision

University College London Dept. of Space & Climate Physics

The Mullard Space Science Laboratory

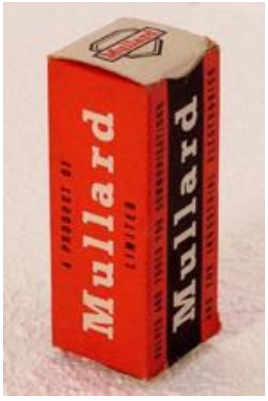
Sir Harrie Massey (1908-1983) was the founder of Space Science in the UK. In 1953 he was Head of the Physics Department at UCL and was offered the opportunity to use sounding rockets for upper atmosphere research.

In 1965 Mullard Ltd made a donation to UCL to establish the Mullard Space Science Laboratory. The site in Holmbury St Mary was purchased, renovated and formally opened in 1967. Its first director was Sir Robert Boyd (1922-2004).

Since MSSL was established we have participated in over 35 satellite missions and over 200 rocket experiments. We have flown instruments on spacecraft built by all of the major space agencies (NASA, ESA, Japan, USSR/Russia, China, …)

Also known as UCL's Department of Space and Climate Physics.

The UK's largest university-based space research group



Mullard

Matched EL34 Vacuum Tubes
by Russian manufacturer,

Svetlana

Captain Stanley R. Mullard

Mullard Space Science Laboratory

Staff Compliment:	**185**
Of which :	
Academic staff :	**25**
PhD students :	**37**
Research staff :	**24**
Technical staff :	**80**
Operations staff :	**8**
Administration :	**11**

Funding sources

- STFC
- ESA
- EU-FP7
- NERC
- EPSRC
- RC UK
- TSB
- Contract
- Consultancy
- UCL

Academics have a modest teaching load
Academics have a considerable project load

A Research Department

MSSL Research & Engineering Groups

MSSL is a unique interdisciplinary department within University College London:

- **close coupling between space science and engineering disciplines**
- **several research groups all linked by the common theme of access to space:**

Astrophysics
Solar/Stellar Physics
Space Plasma Physics
Climate Extremes
Detector Physics (cryogenics)
Planetary science
Theory
Imaging*

engineering groups:

Electronic Engineering
Software Engineering
Mechanical and Thermal Engineering
Instrument Science

- **Support/other groups**

Programmes
Administration
Computing
Technology Management
Commercial

*includes Earth Remote Sensing (with Department of Earth Sciences & C

19 Instruments on 13 Spacecraft

Past

- AMPTE
- Ariel V; VI
- Beagle-2
- Cryosat
- Cluster - I
- Coronas-F
- CRRES
- ERS1; 2
- ENVISAT
- EXOSAT
- Giotto
- ISO
- Mars 96
- Moses SR
- Polar
- ROSAT
- SMM
- Spacelab 1; 2
- Yohkoh

Operational

- Cassini
- Cluster - II
- Cryosat-2
- Double Star
- Herschel
- Hinode – EIS
- Hinode – FPP
- INTEGRAL
- Mars Express
- SOHO
- SWIFT
- Venus Express
- XMM-Newton OM
- XMM-Newton RGS

Future

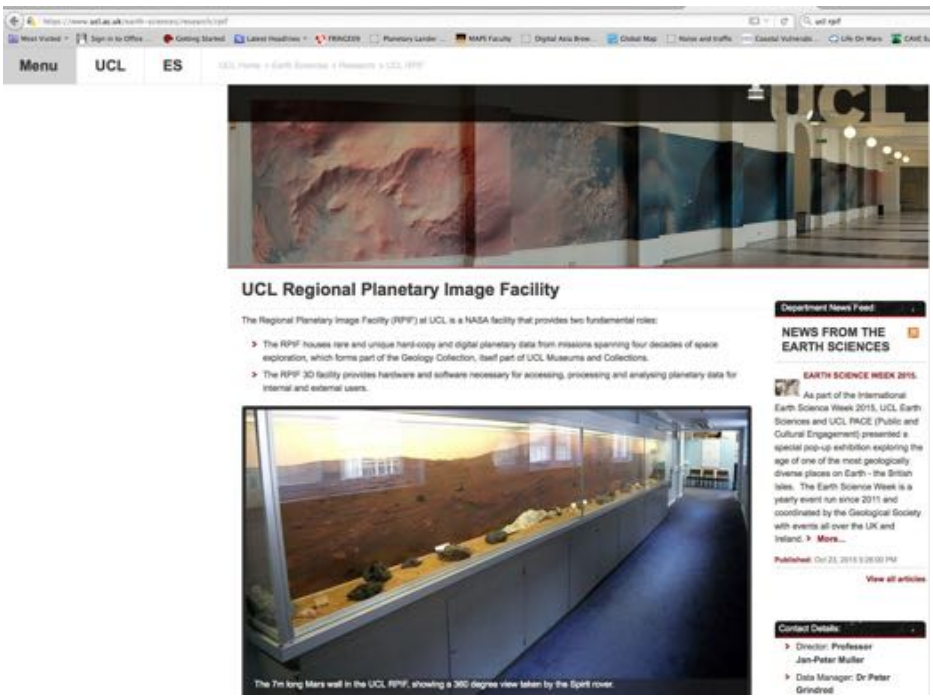
- Astrosat
- Cross-scale
- Euclid
- ExoMars
- GAIA
- JWT
- Laplace/Tandem
- KuaFu
- Plato
- Solar Orbiter
- Sentinel 1 & 3

MSSL's Space Mission involvements

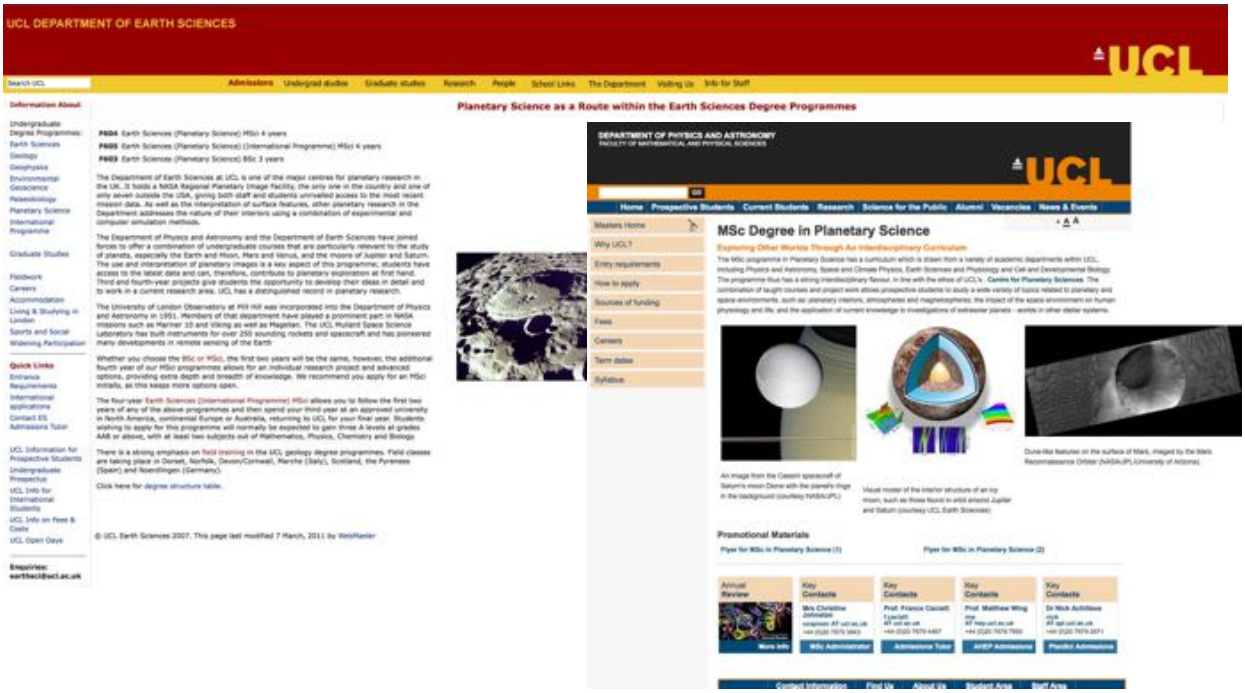
Planetary Research at UCL

- UK NASA RPIF created in 1980 and on its present site since 1999
- UCL has the largest number of academic staff, researchers and PhD students working in planetary research in the UK (≈90)
- UCL started the first undergraduate programme in Planetary Science in Europe based in Earth Sciences and began a MSc in Planetary Science in October 2010
- An inter-departmental Centre for Planetary Sciences (CPS) was established to try to capitalise on all of this activity
- CPS includes members of UCL Earth Sciences, Physics & Astronomy and MSSL (Space & Climate Physics) as core with links to Biochemistry, Mathematics, Civil, Engineering & Geomatic Engineering)
- CPS is part of a wider "Origins" programme within the MAPS (Mathematical and Physical Sciences) Faculty
- RPIF is located inside the CPS. The CPS includes post-docs & PhD
- CPS and RPIF are moving in 7/2016 due to major restructuring work at UCL

UCL RPIF physically co-located with CPS within UCL Earth Sciences



RPIF is critical to teaching and learning at UCL in its teaching programmes



UK NASA RPIF corridor display for visitors

RPIF News on Facility Usage

- **Visitors: every Wednesday for university interviews in term-time**
  - **RPIF Open Day: ~100 (November 2011- 2013)**
  - **University interviewees: ≈400 (Sept. 2011 – November 2013)**
  - **School students: 30 p.a.**
- **Magic Planet spherical display**
  - **25 different users since purchase in 2008**
  - **5 users in 2013**
  - **On loan for 10 of last 12 months**
- **Outreach**
  - **Supported exhibition "Your Universe", UCL (every few months)**
  - **Many media requests handled, especially related to MSL: e.g. BBC, Sky News, New Scientist, CNN, Al Jazeera, The Guardian**

RPIF as a 3D Imaging Centre

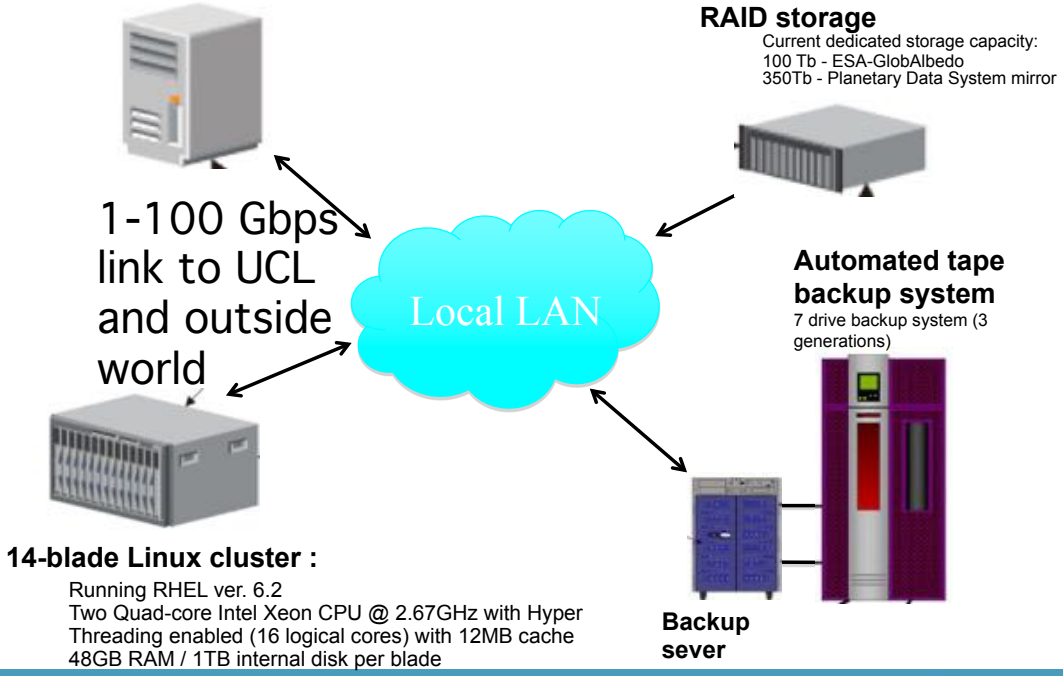
- **In addition to providing access to photographic, map and specialist technical reports (NASA-SP, NASA-TM, LPSC proceedings not online) UK RPIF is focusing on developing a world-class 3D Imaging Centre**
- **This consists of "state-of-the-art" 3D visualisation facilities linked by high-speed (>>1Gbps) data-store containing PDS mirror and eventually co-registered orthorectified imaging datasets from ESA and NASA**
- **Have established a mirror PDS Imaging Node data collections, with all orbiter and rover imaging data.**
- **EU-FP7 PRoViDE2 funded (2.5M€) from 1/13-12/15 with UCL providing the processing facilities for merging all MER imaging data into a seamless 3D visual environment by combining HiRISE and wide baseline MER PanCam/NavCam. Builds on previous EU-FP7 PRoViSG & PRoViScout in close collaboration with JPL**
- **STFC (UK) funded £500k (0.7M€) from 4/13 to develop technology for automating co-registration and orthorectification and subsequent data mining of time series of coregistered NASA orthoimages from 1976-2016 to ESA/DLR HRSC ORIs and DTMs**
- **EU-FP7 iMars project subsequently funded processing of the remaining HRSC, HiRise and CTX stereo into a fused DTM and processing 50% of the Martian surface into a set of time-stamped ORIs and the automated co-registration of all prior data (THEMIS, MOC, VO).**

UCL RPIF 3D Facility – European Facility Open to All

- **Computing RPIF 3D user computing facilities available:**
  - **1 Mac Pro (2009) ISIS, ENVI/IDL (+CAT), Fledermaus**
  - **1 iMac (2013) ISIS, ENVI/IDL**
  - **1 stereo PC (2009) BAE SocetSet 5.4, ArcGIS10**
  - **1 stereo PC (2013) BAE SocetSet 5.6, ArcGIS10**
- **European equivalent of USGS/NASA Planetary Photogrammetry Guest Facility**
- ***Planetary Data Workshop (at EPSC2013)***
  - **Funded by UK Space Agency Research Fellowship (Grindrod)**
  - **13 attendees, mostly UK (due to advertising)**
  - **Tutorials on:**
    - » **1. Stereo DTM production (CTX + HiRISE) using SocetSet**
    - » **2. OMEGA data and processing (by ESA PSA representative)**

RPIF 3D visualisation : produce and visualise 3D models of anywhere in the solar system

MSSL RPIF-3D facility for large-scale imaging projects: Previously used for creating 15 year 1km Earth land albedo and 15 years of spectral BRDF/Albedo at 0.5km for Earth



Key elements (1) from RPIF-3D for training workshop

- **Introduction to 3D imaging for Mars & the Moon using the USGS-ISIS and SOCET® system**
- **Visualisation of 3D images using PRo3D® and Fledermaus**
- **Introduction to hyperspectral image processing for mapping mineralogy from the NASA CRISM**
- **Introduction to 3D mapping (iMars CASP-GO) and Automated Co-Registration & Orthorectification (iMars ACRO)**
- **Introduction to COTS ARCgis® and open source QGIS**
- **Introduction to citizen science and an experiment on change detection**

PRoViDE:

Planetary Robotics Vision Data Processing and Fusion

G. Paar (1), J.-P. Muller, Y. Tao (2), T. Pajdla (3), M. Giordano (4), E. Tasdelen (5), Karatchevtseva (6), C. Traxler, G. Hesina (7), L. Tyler, D.P. Barnes (8), S. Gupta (9), K. Willner (10)

(1) JOANNEUM RESEARCH, A (Gerhard.paar@joanneum.at); (2) University College London, UK; (3) Czech Technical University, CZ; (4) University of Nottingham, UK; (5) Technical University Berlin, D; (6) Moscow State University of Geodesy and Cartography, RUS; (7) VRVis Zentrum für Virtual Reality und Visualisierung Forschungs-GmbH, A; (8) Aberystwyth University, UK; (9) Imperial College of Science, Technology and Medicine, UK.
(10) German Space Center, Berlin, D

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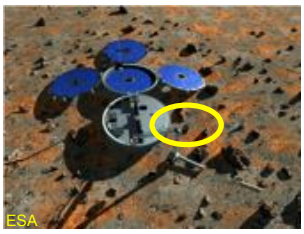
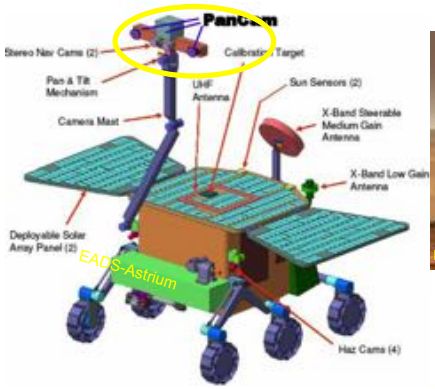
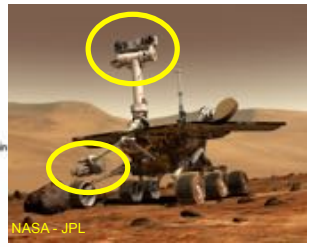
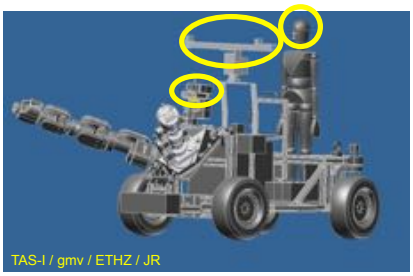
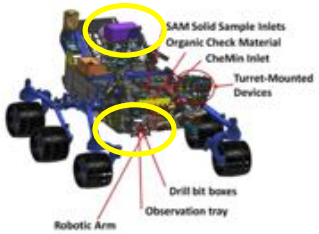
Dozens of Vision Sensors on Planets
Hundred Thousands of Images











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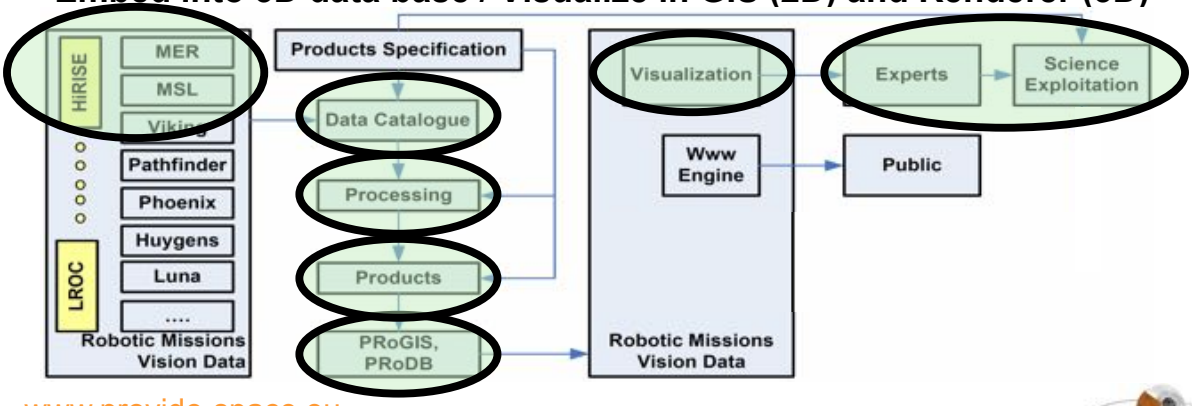
PRoViDE Objectives & Components

- Most rover images are only processed under mission-pressure without further exploitation →
- Harvest literally all [available] Planetary surface-captured vision data
- Process in 3D Vision terms for further scientific exploitation
- Embed into 3D data base / Visualize in GIS (2D) and Renderer (3D)



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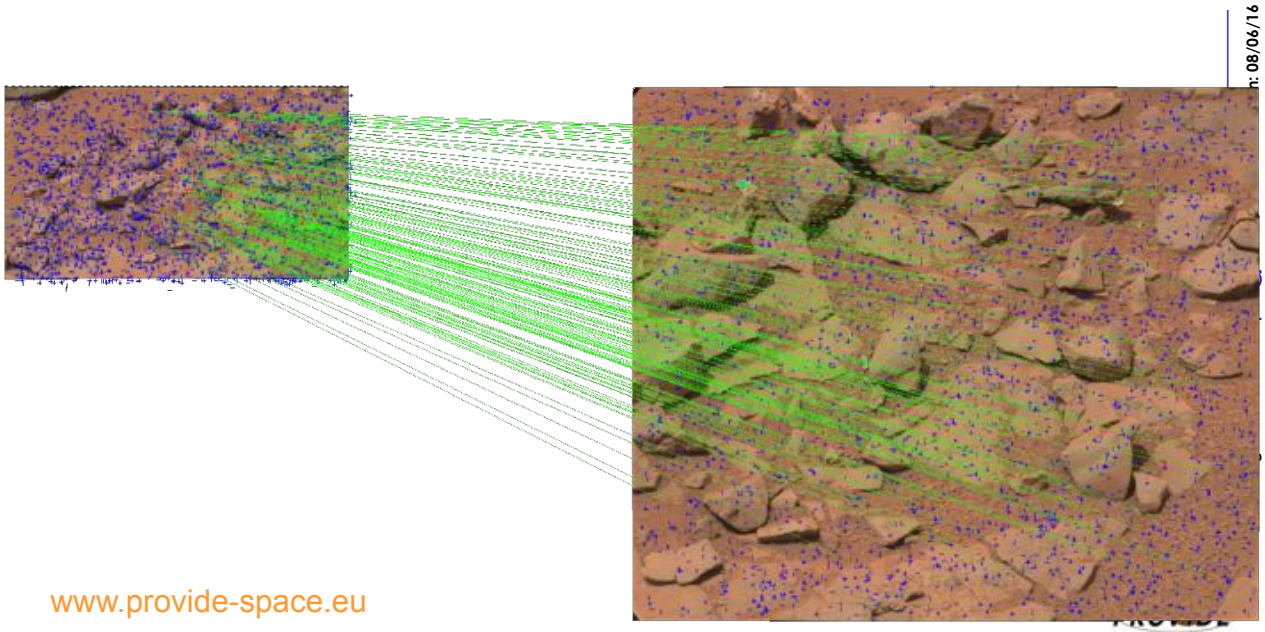
MSL Mastcam (close range) left and right Input Images Examples

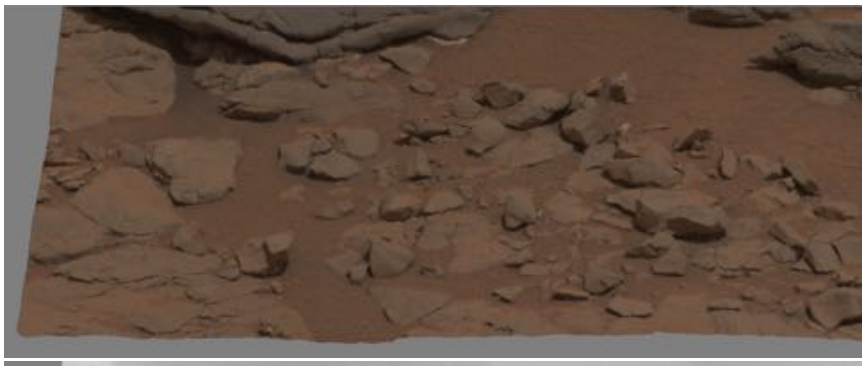
- **Left**
  - **769x433 px**
- **Right**
  - **1402x1402 px**

Reconstruction Process pre-registration

- **Sparse point matching**

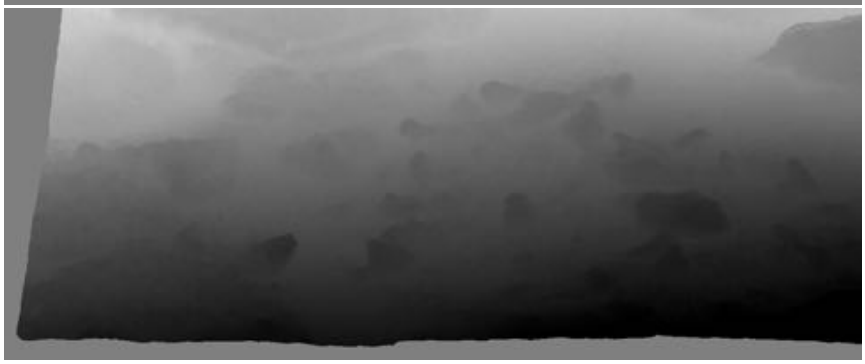


Reconstruction Process
Stereo reconstruction and mosaicking



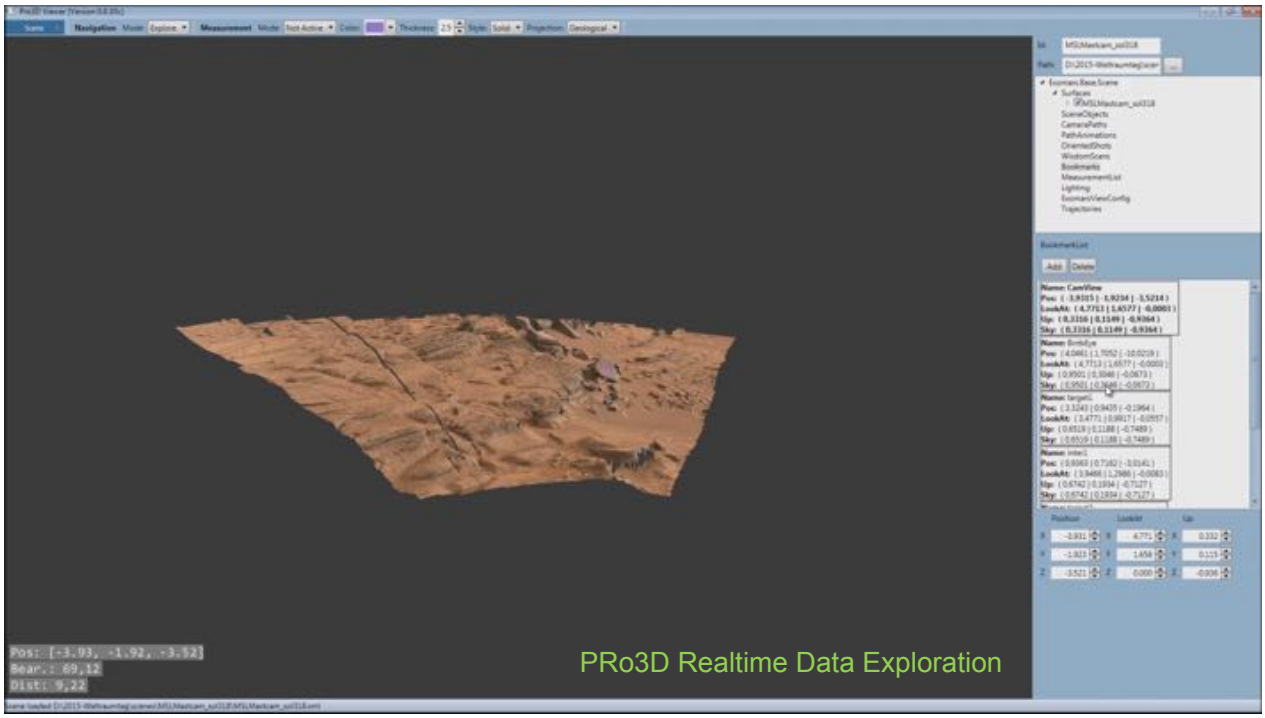
Cutout of reconstruction

Ortho Image



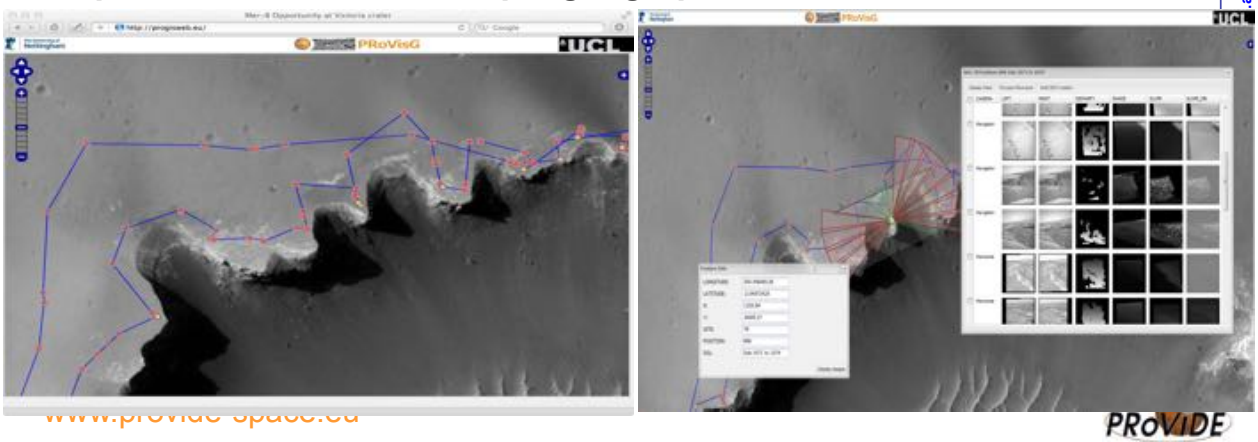
DEM
(Distance Map)

Combination of 99 Mastcam Pairs

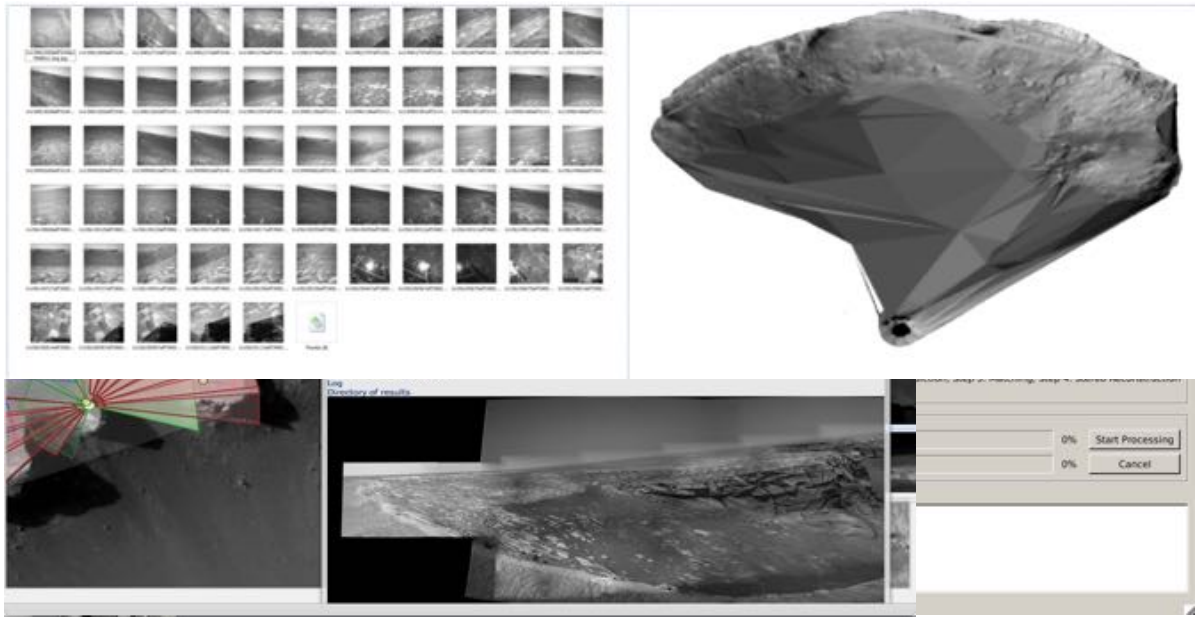


Interactive Web-GIS: PRoGIS

- PRoViDE muti-resolution co-registered dataset has been inserted into an interactive Web-GIS system, i.e. PRoGIS (http://progisweb.eu).
- The public will gain access to the Mars rover mission data (via UCL-MSSL's PDS mirror) and our seamlessly interconnected products within this unique geographical context.

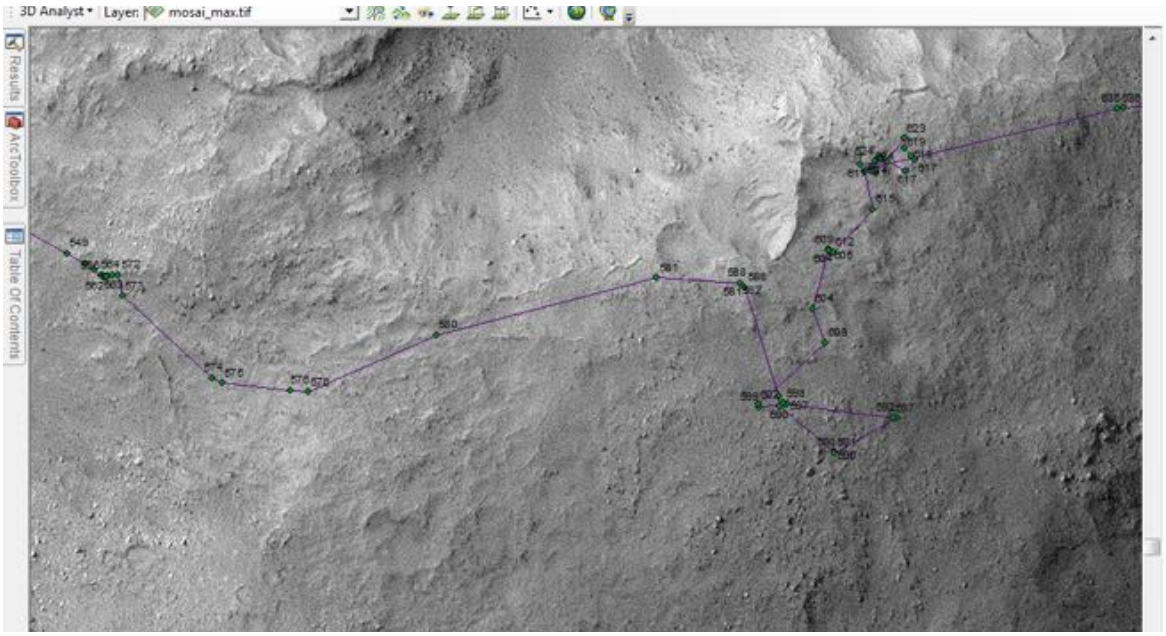


Interactive Web-GIS: PRoGIS



Gerhard.paar@joanneum.at

Super-resolution (from 25cm to 5cm) (Example shown of MER-A)



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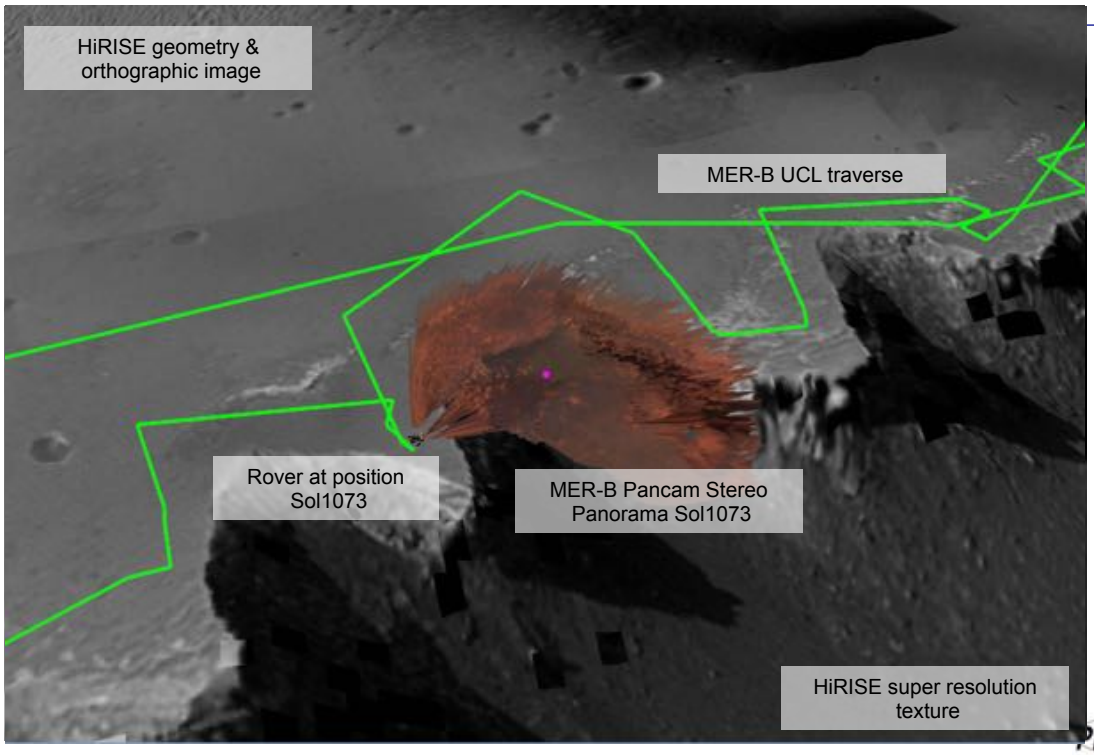
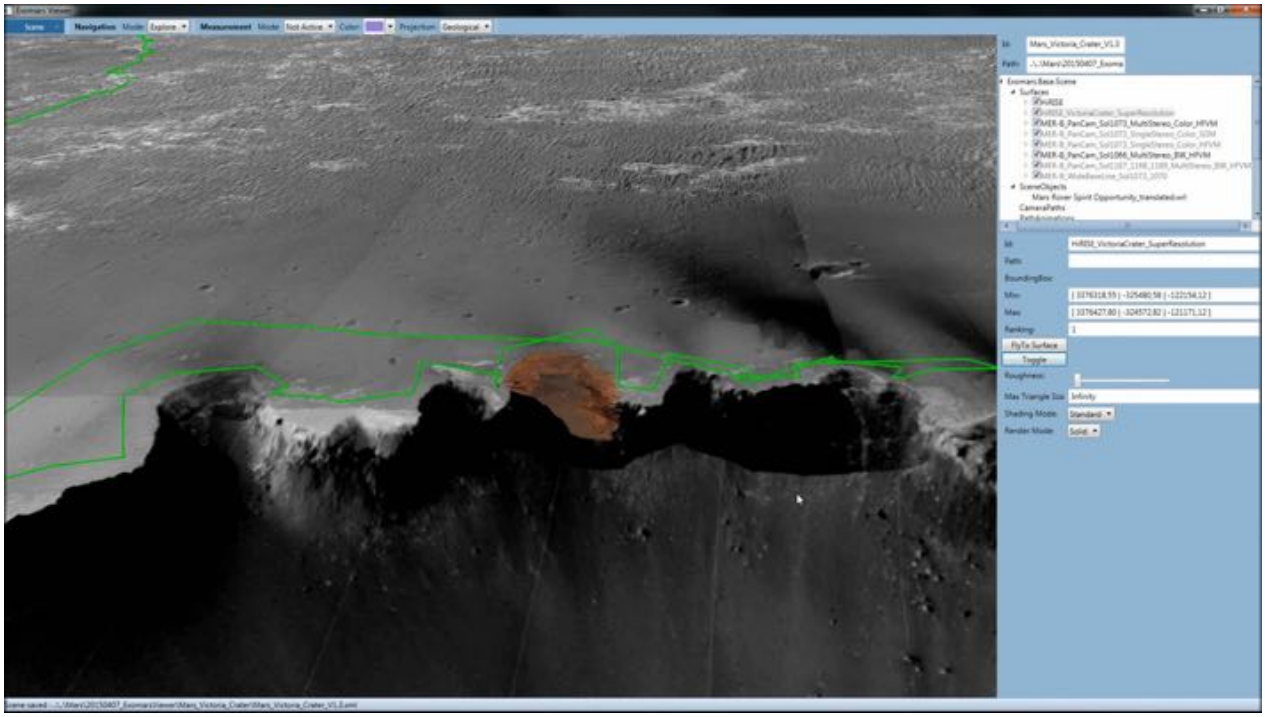
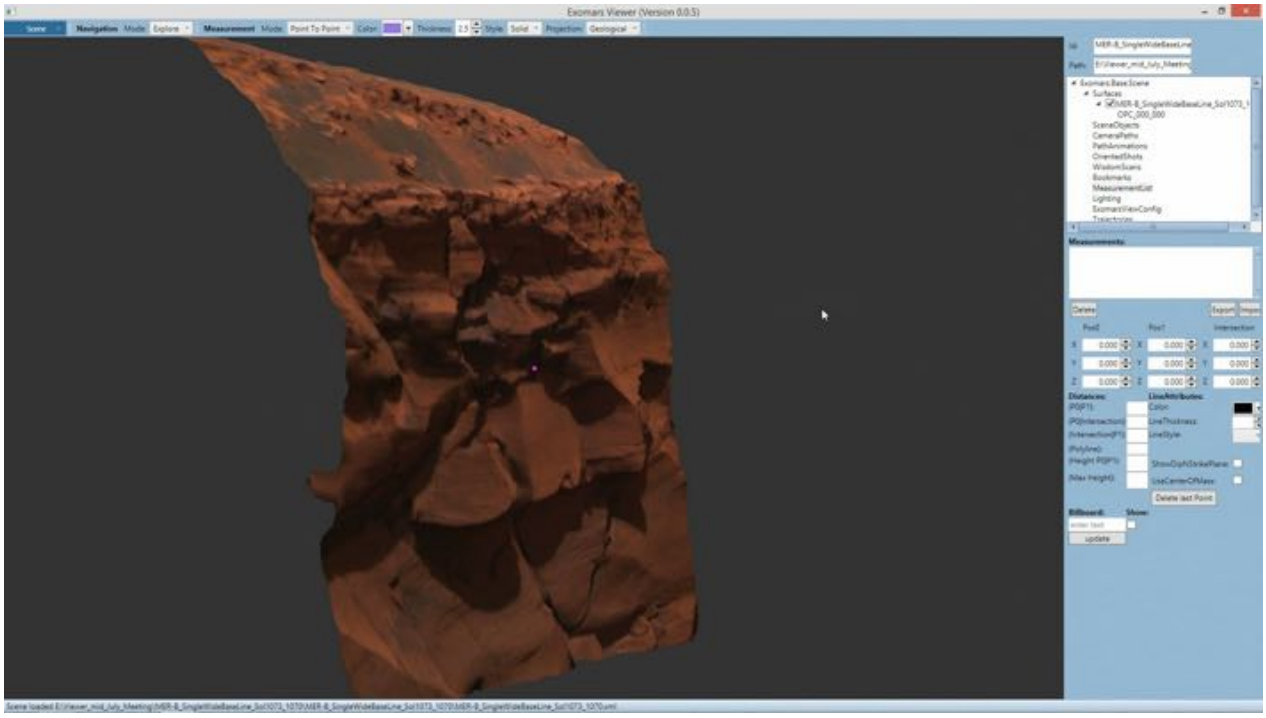
Co-registration & Fusion result



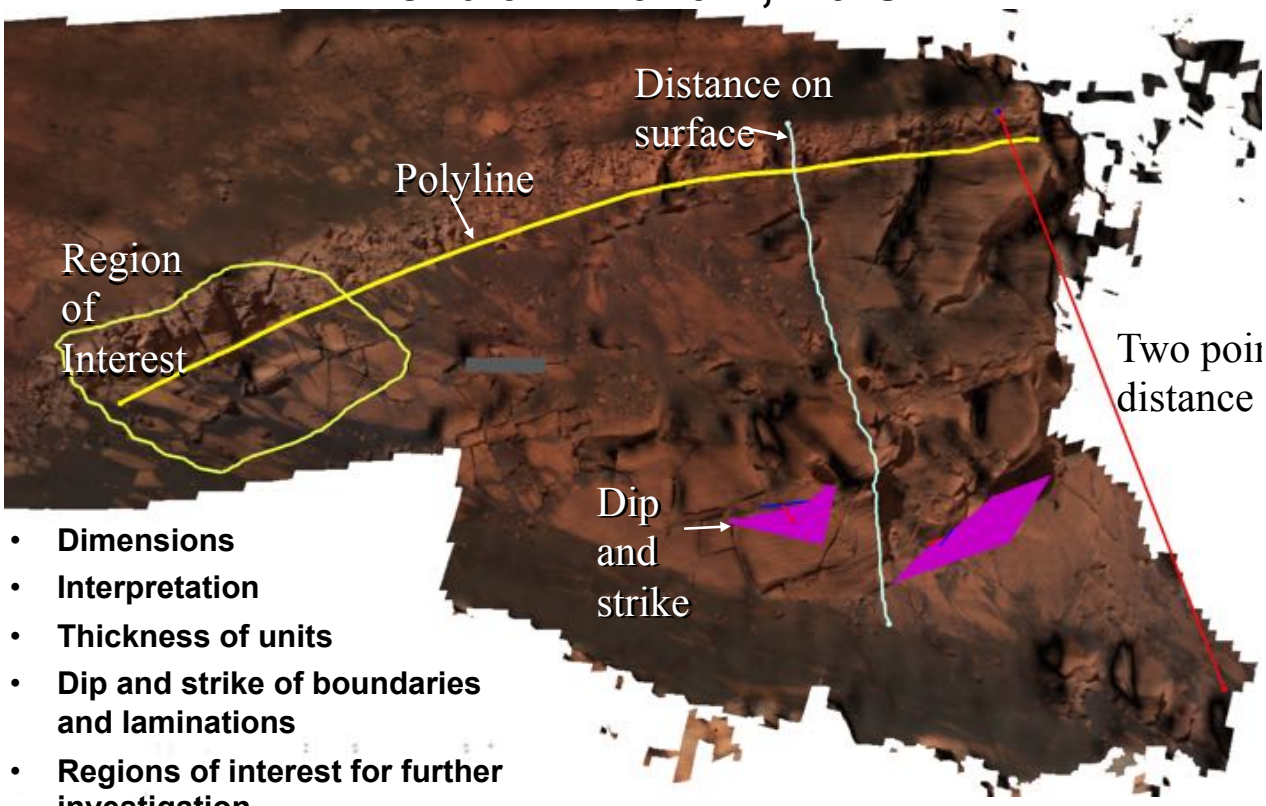
PRo3D: Embedding in full context of HiRISE DEM:Tens of Gbytes of data / scene



PRo3D – Measurements



PRo3D – 3D measurements at Victoria Crater, Meridiani Planum, Mars.



- Dimensions
- Interpretation
- Thickness of units
- Dip and strike of boundaries and laminations
- Regions of interest for further investigation

Key Elements (2) for training workshop from PRoViDE

- Find out what images have been captured by NASA planetary rovers?
- Discover what new 3D imaging products are available derived from these rovers
- Explore the landscape using super-resolution imagery (from 5-12.5cm/pixel)
- Perform 3D measurements of geological features to learn how 3D imaging products can be employed to explore a landscape

iMars - Analysis of Mars multi-resolution images using auto-coregistration, data mining and crowd source techniques : A Mid-Term Report

Jan-Peter Muller*

V. Yershov, P. Sidiropoulos, Y. Tao (UCL-MSSL),

K. Gwinner, K. Willner, L. Fanara, M. Währlisch (DLR),

S. van Gasselt, S. Walter, B.P. Schreiner, R. Steikert (FUB),

A. Ivanov, F. Cantini (EPFL), J.-R. Kim, W.-T. Chen (UoS),

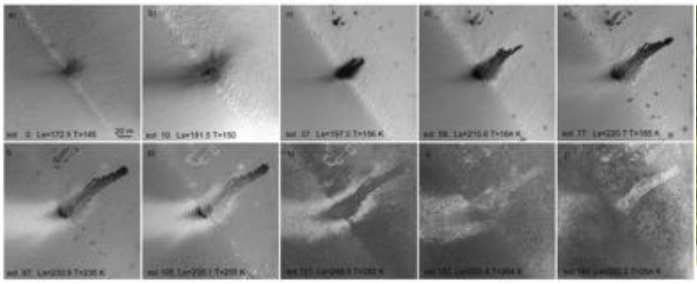
R. Houghton, J. Wardlaw, J.G. Morley, S. Bamford (UNOTT)

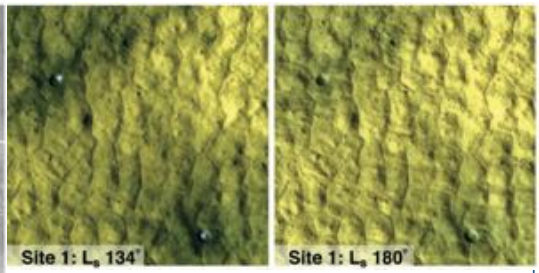
*Co-ordinator, EU-FP7 iMars consortium

iMars Objectives

- To explore changes in the Martian surface since the start of robotic exploration using automated data mining techniques and crowd-sourcing from
- HRSC OrthoRectified Images (ORIs) and Digital Terrain Models (DTMs) as base images and
- Automated co-registration of NASA orbital imagery together with higher resolution DTMs from CTX and HiRISE to these HRSC ORI/DTMs
- Providing data analysis tools, stacks of co-registered data and automated data mining results through an OGC-compliant webGIS to scientific teams led by members of the consortium

Examples of changes on the Martian surface

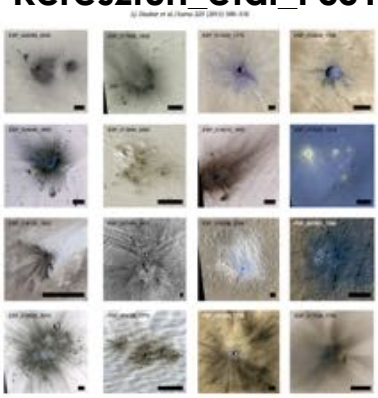


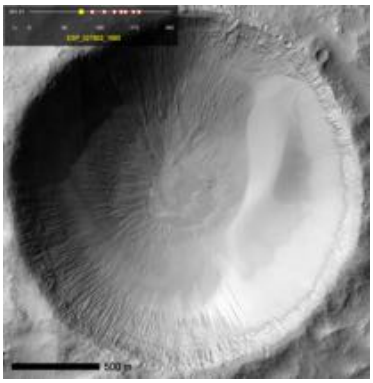


Kereszturi_etal_PSS11

Bryne_etal_Science09

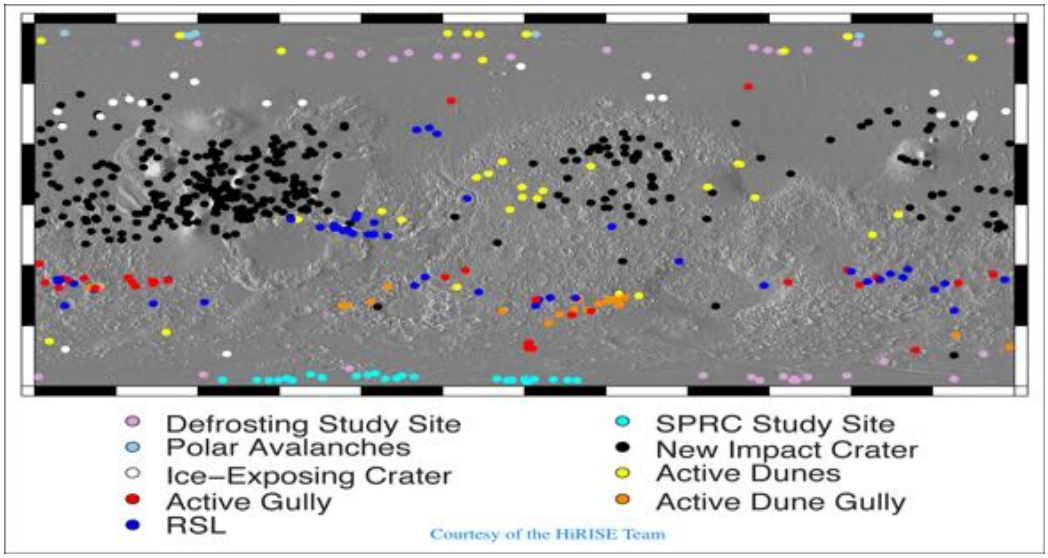
Daubar et al., Icarus 2013





Courtesy of HiRISE team

Changes manually confirmed using only HiRISE images



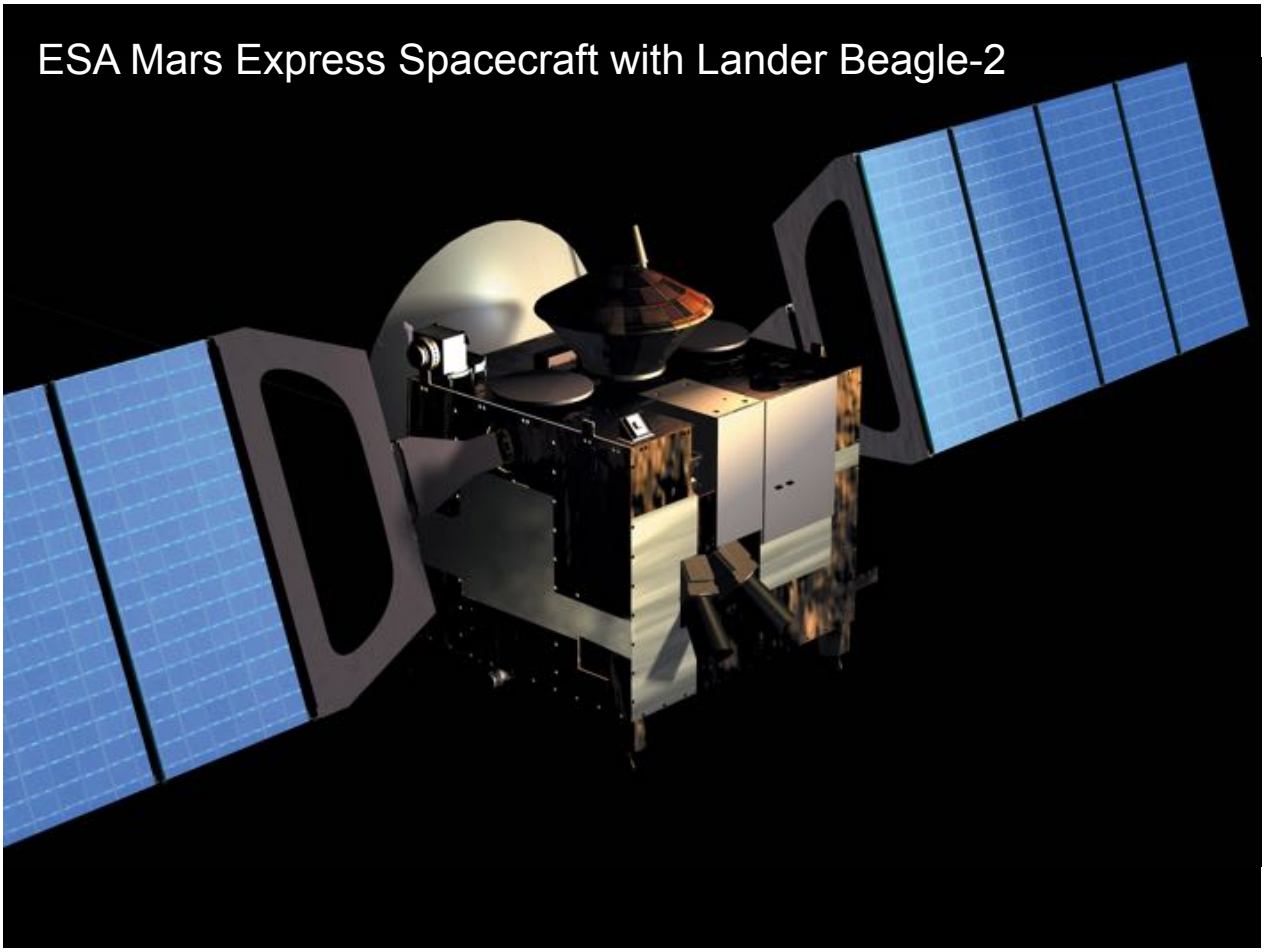
What dynamic features can be observed ≤100m?

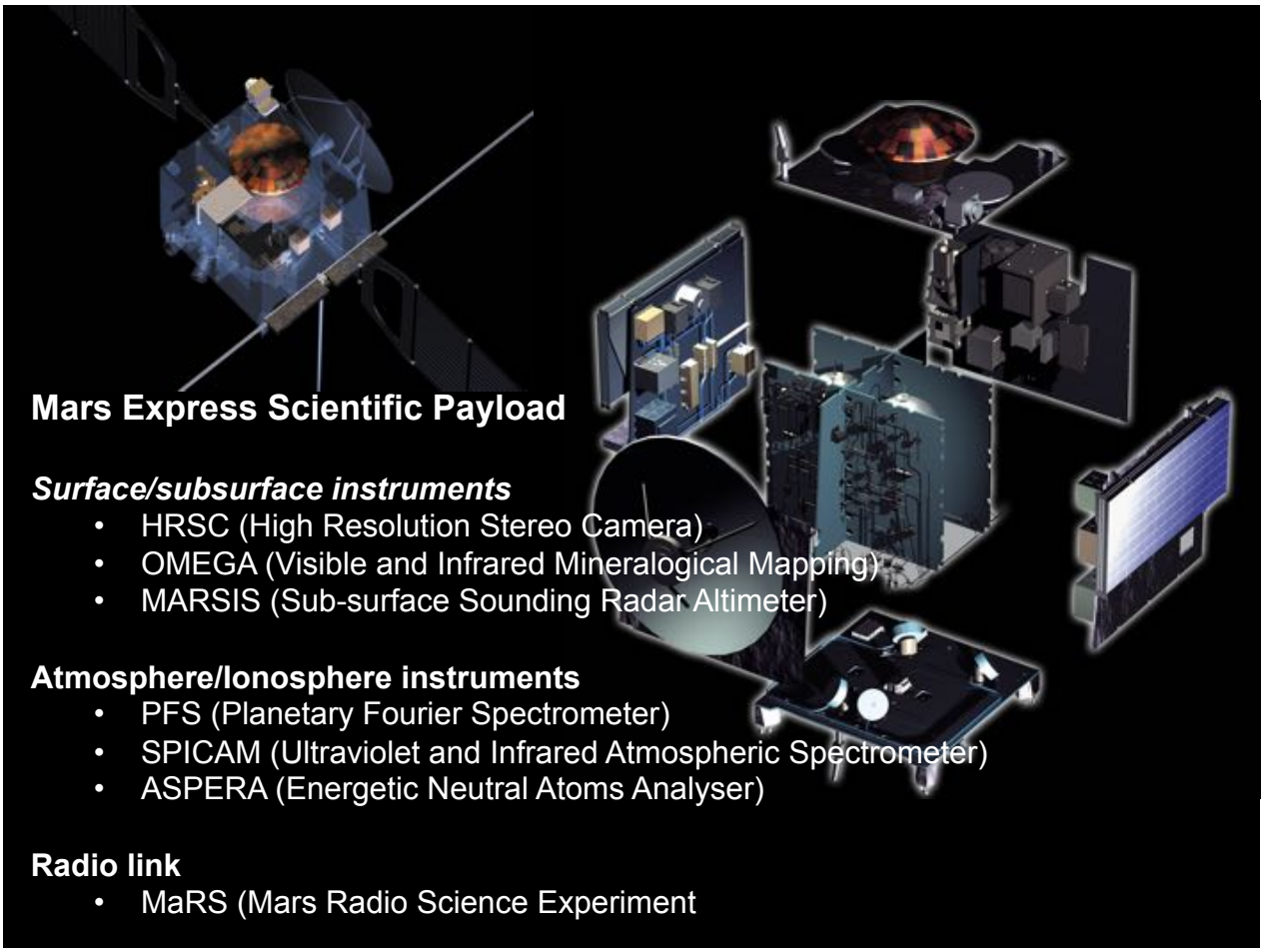
FEATURE	SCALE 1 – <10 m[a]	10 – <50 m[b]	50 – <100 m[c]	100 – <1000 m[d]
Polar Pits	•			
Avalanches		•	•	•
Polygons	•	•		
RSL	•	•		
Swiss Cheese Terrain		•	•	
Active Gullies	•	•	•	
Dunes	•	•	•	
Impact Craters	•	•	•	•
Dust Devils	•	•	•	
Spiders	•	•		

a: MRO/HiRISE, potentially some MRO/CTX and MGS/MOC cPROTO
b: MRO/CTX and MGS/MOC, MO/THEMIS VIS, MEx/HRSC, VO Imaging
c: MO/THEMIS VIS, MEx/HRSC, VO Imaging
d: MO/THEMIS VIS, MO/THEMIS IR, MEx/HRSC, VO VIS Imaging, M9 VIS

iMars Scientific Context

- The surface of Mars is NOT static, this is the lesson that was learnt from repeat observations from MOC and more recently for CTX and HiRISE
- There are now almost 40 years of repeat observations of the Martian surface
- These changes indicate that the surface is more active
- Most changes due to surface-atmosphere interactions





Mars Express Scientific Payload

Surface/subsurface instruments

- HRSC (High Resolution Stereo Camera)
- OMEGA (Visible and Infrared Mineralogical Mapping)
- MARSIS (Sub-surface Sounding Radar Altimeter)

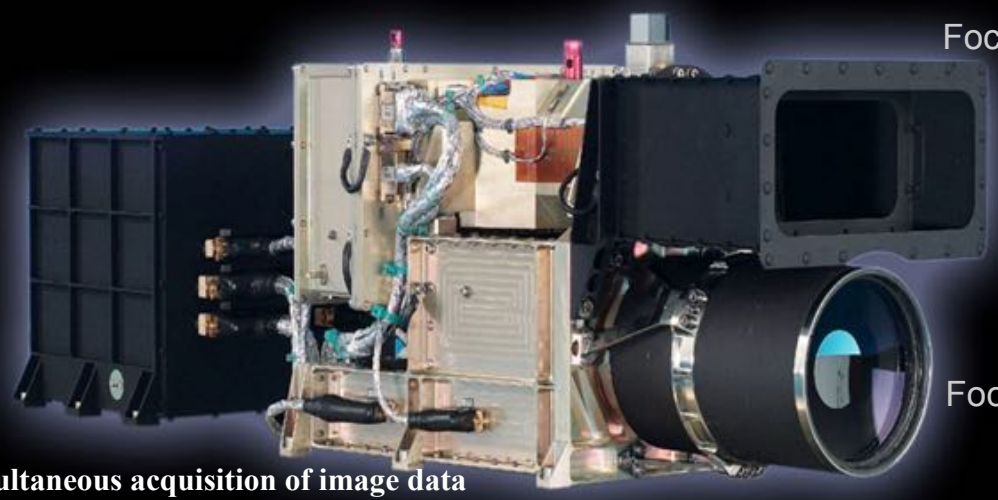
Atmosphere/Ionosphere instruments

- PFS (Planetary Fourier Spectrometer)
- SPICAM (Ultraviolet and Infrared Atmospheric Spectrometer)
- ASPERA (Energetic Neutral Atoms Analyser)

Radio link

- MaRS (Mars Radio Science Experiment

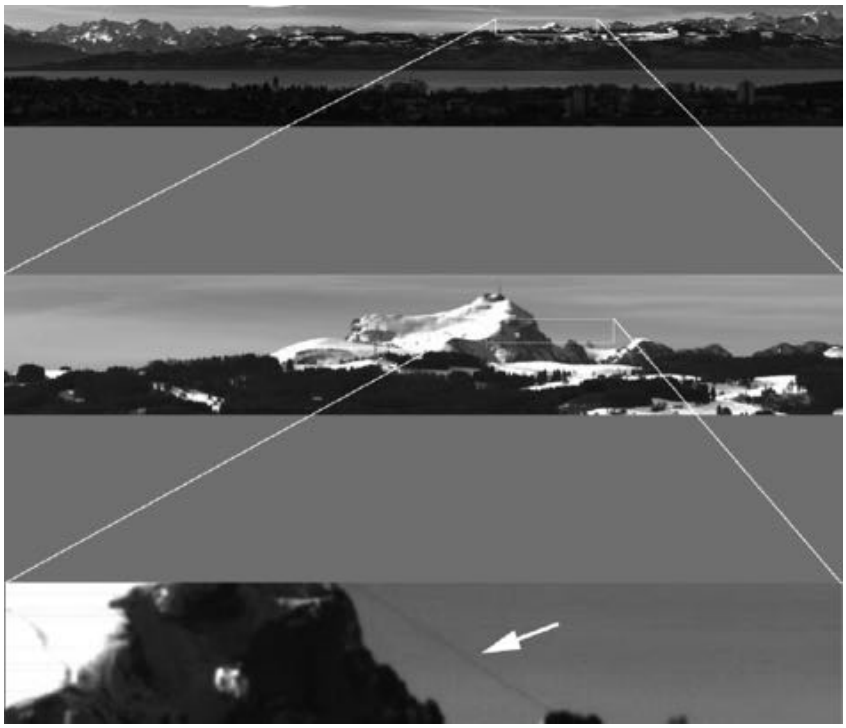
HRSC and SRC – Technical Parameters



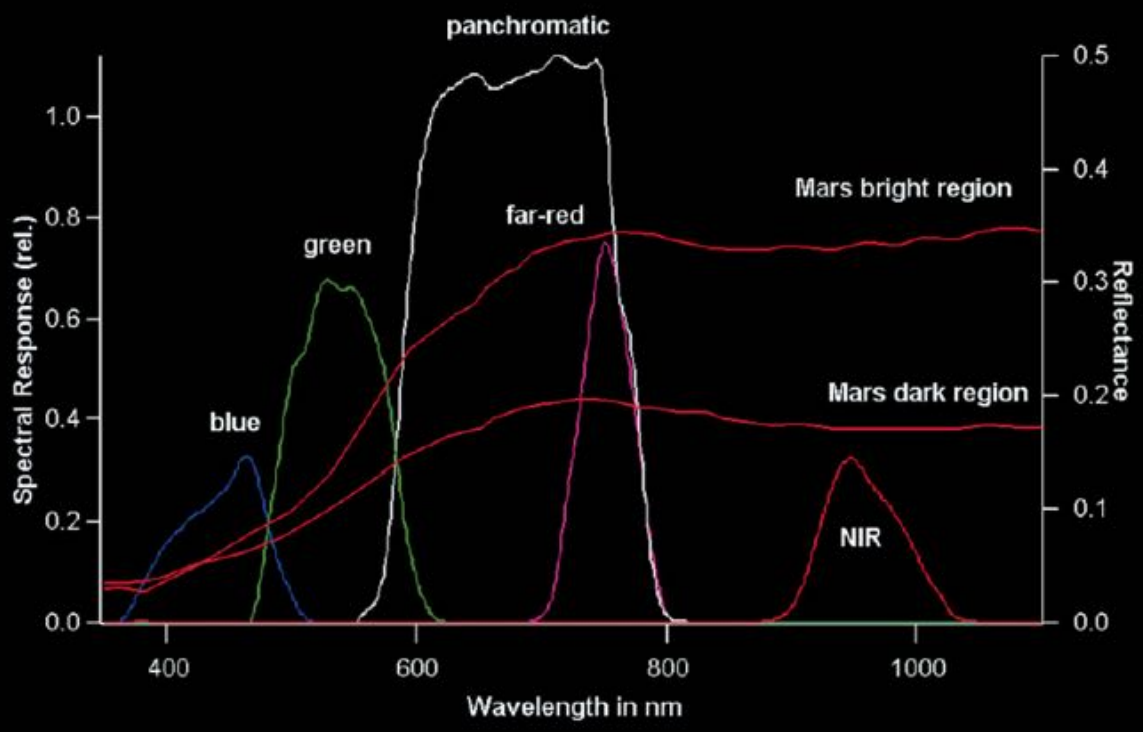
Simultaneous acquisition of image data

- **High resolution : Nadir-Sensor, 10 m/Pixel from 250 km Altitude**
- **Stereo: 4 Sensors, 10-20 m/Pixel from 250 km Altitude**
- **Color: 4 Sensors, red, green, blue, near Infrared**
- **Max. Resolution (SRC): 2-3 m/Pixel from 250 km**
- **Output-Datarate: 25 Mbit/s, On chip-Compression**
- **Mass: 19.6 kg**

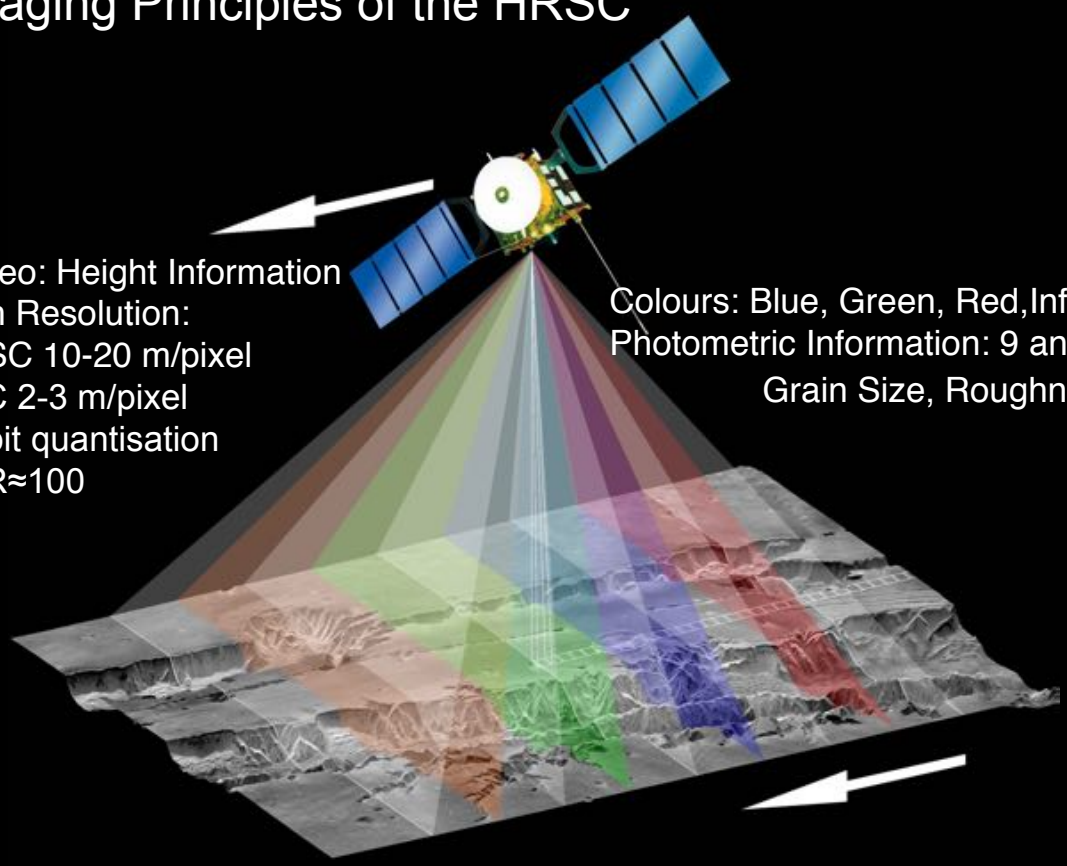
What did HRSC see from a laboratory near Munich in the Alps, 80km away?



HRSC: Spectral Characteristics



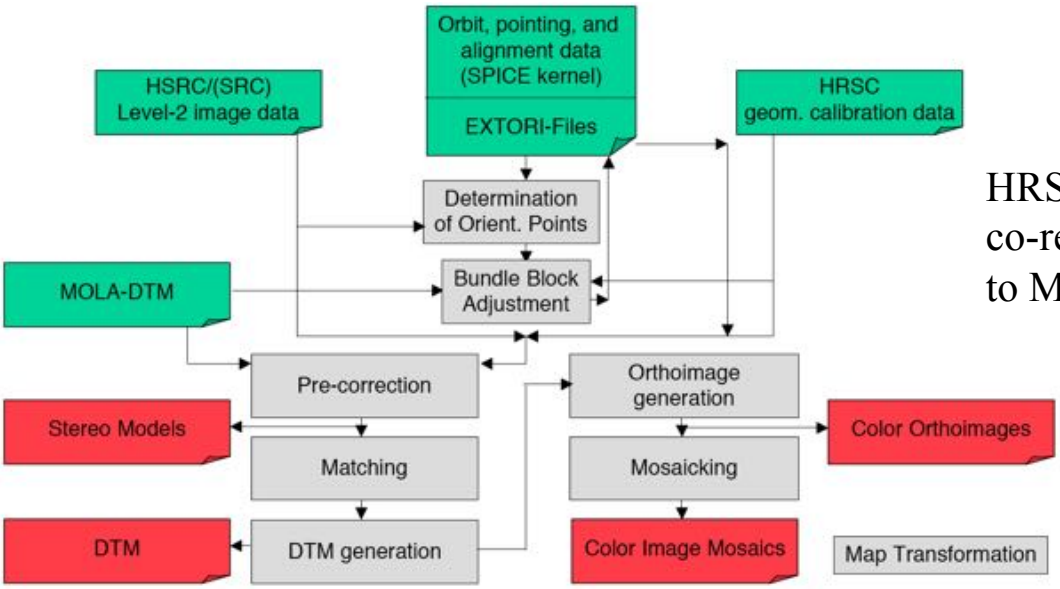
Imaging Principles of the HRSC



Stereo: Height Information
High Resolution:
HRSC 10-20 m/pixel
SRC 2-3 m/pixel
14-bit quantisation
SNR≈100

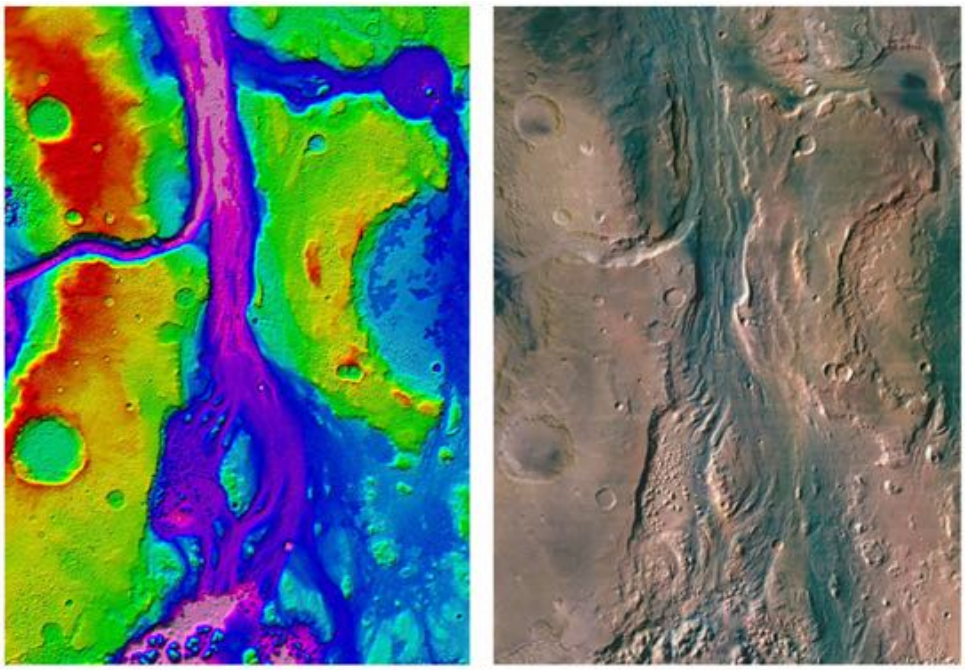
Colours: Blue, Green, Red,Infrared
Photometric Information: 9 angles
Grain Size, Roughness

HRSC stereo DTM production system: systematic production underway (50-150m DTMs) at DLR with bespoke DTM mosaics at UCL (30-75m)



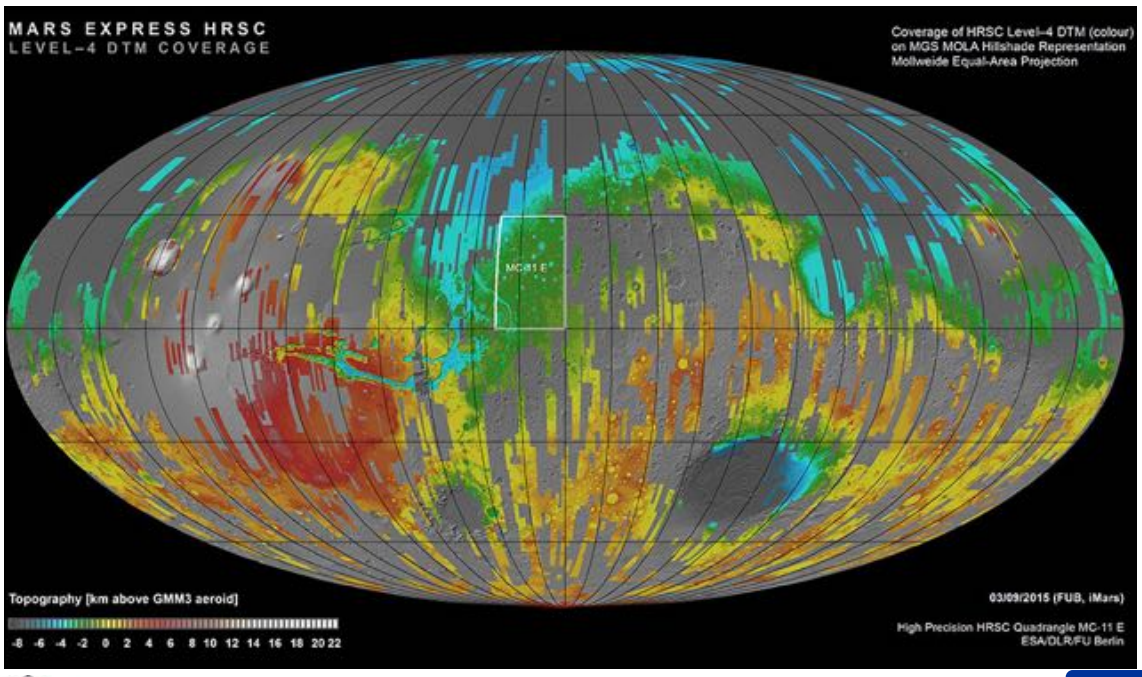
HRSC co-registered to MOLA

Catastrophic flooding : Iani Vallis HRSC 50m DTM and multispectral image



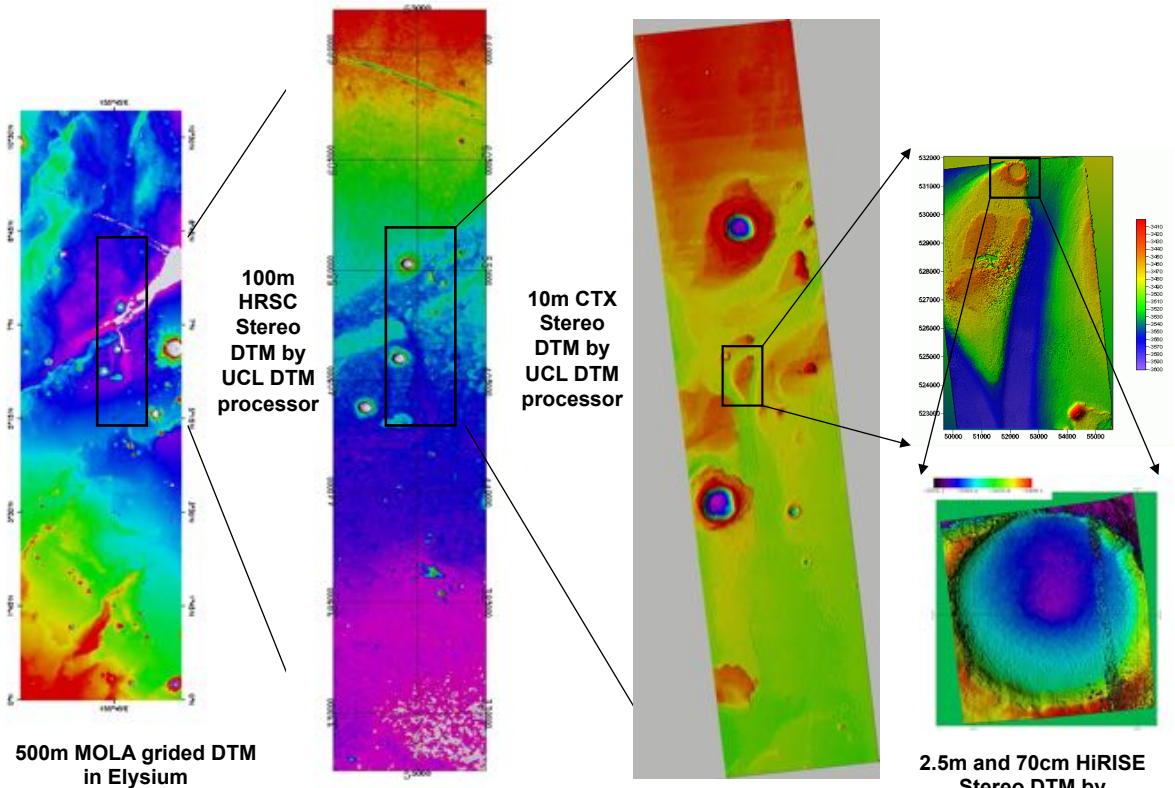
Warner, Gupta, Muller et al, Geology (2010, 2011)

Global HRSC DTM+ORI coverage (DLR+FUB)



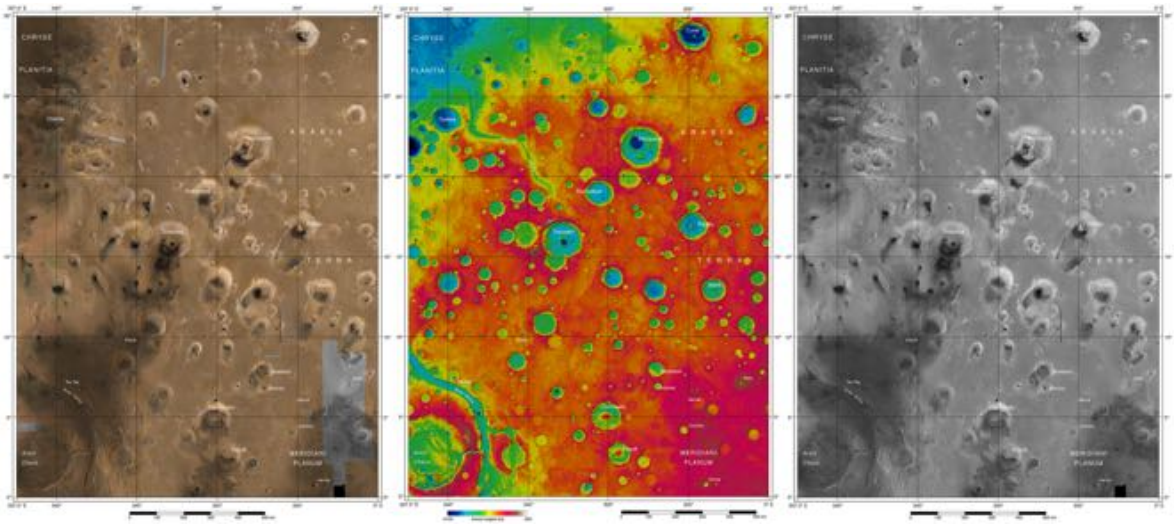
K. Gwinner, E. Hauber, R. Jaumann, G. Michael, H. Hoffmann, and C. Heipke, *EGU General Assembly*, Apr. 2015; EPSC15

Multi resolution DTM from MOLA, HRSC, CTX, HiRise: Elysium/Athabasca Vallis



Kim & Muller, Planetary Space Science 09

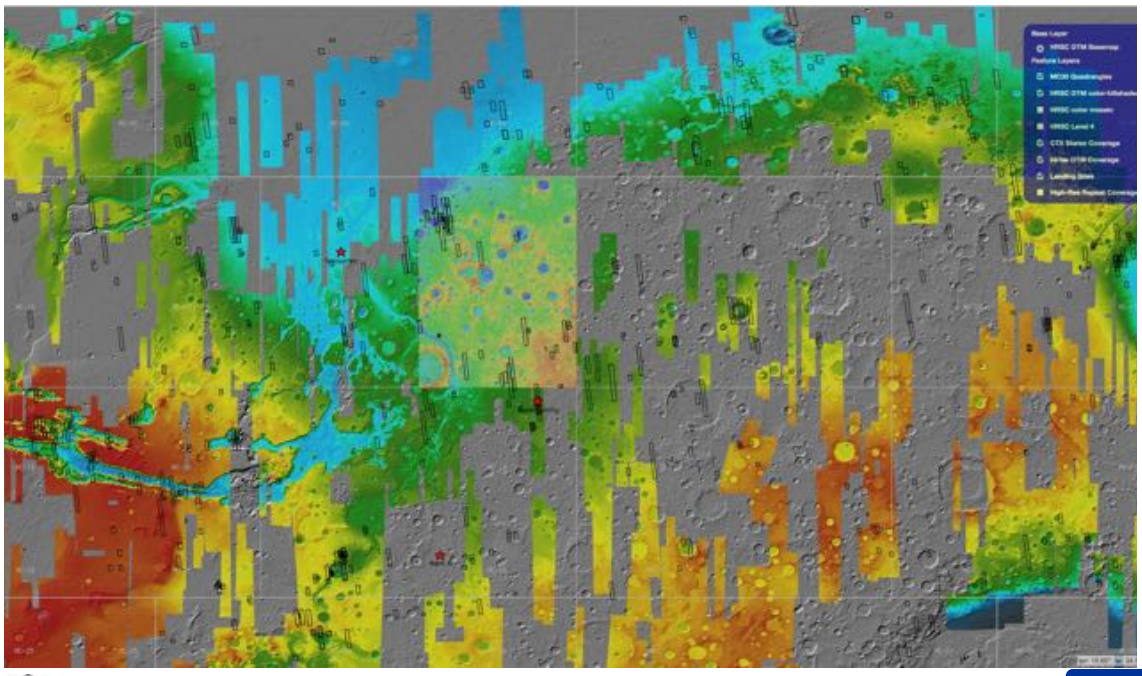
Large area HRSC mosaics: MC11E (DLR)



HRSC 50m colour mosaic | HRSC colourised + Hill-shaded 50m DTM | HRSC 12.5m panchromatic mosaic

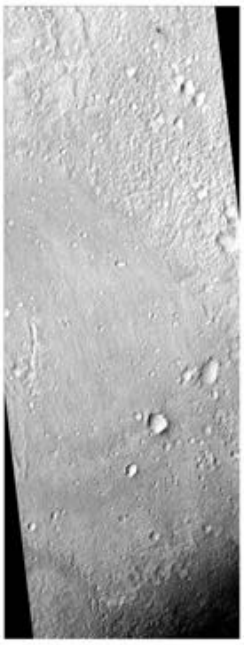
N.B. After 10 years of Mars Express HRSC observations, there are now sufficient numbers of HRSC orbits to generate large-area Mosaic products. This is a very significant step forward for Mars

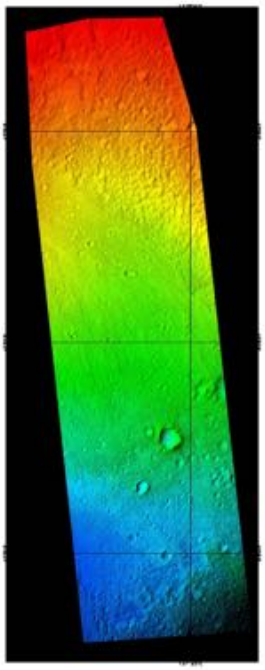
Context of MC11E with HRSC coverage showing CTX + HiRISE stereo (FUB)



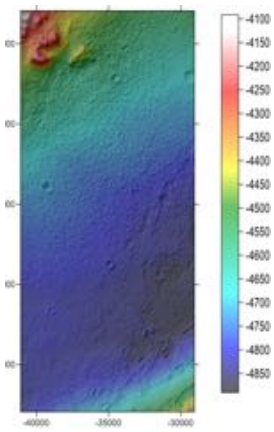
The continuous rectangle is MC-11E, the larger footpri CTX stereo and the smaller footprints, HiRISE stereo

Automated CTX+HiRISE DTM results (UoS)

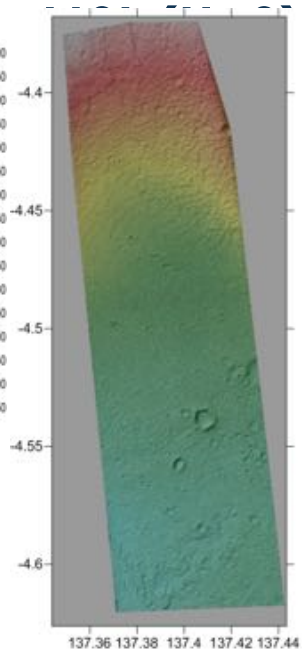




HiRISE ortho & composite image

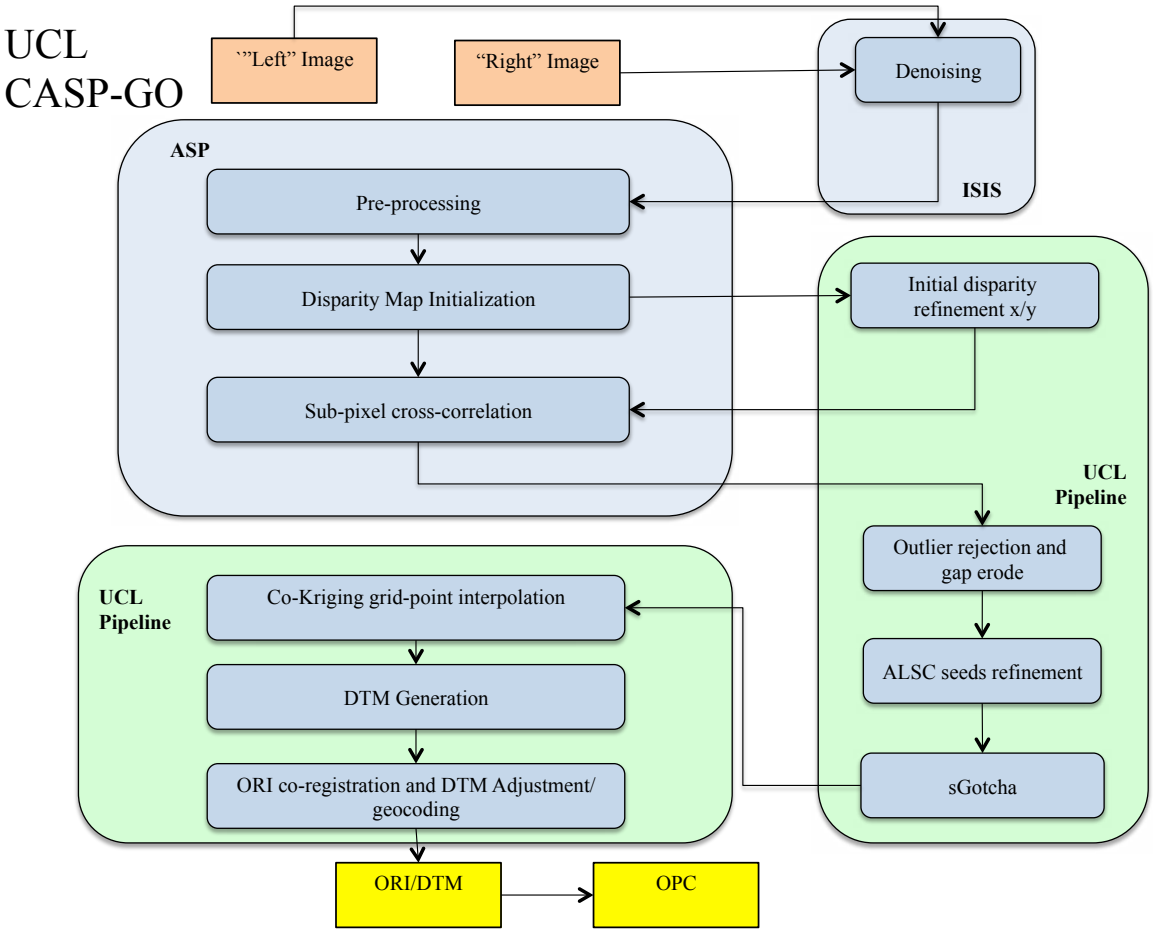


Part of CTX correspond -ing area with HIRISE image

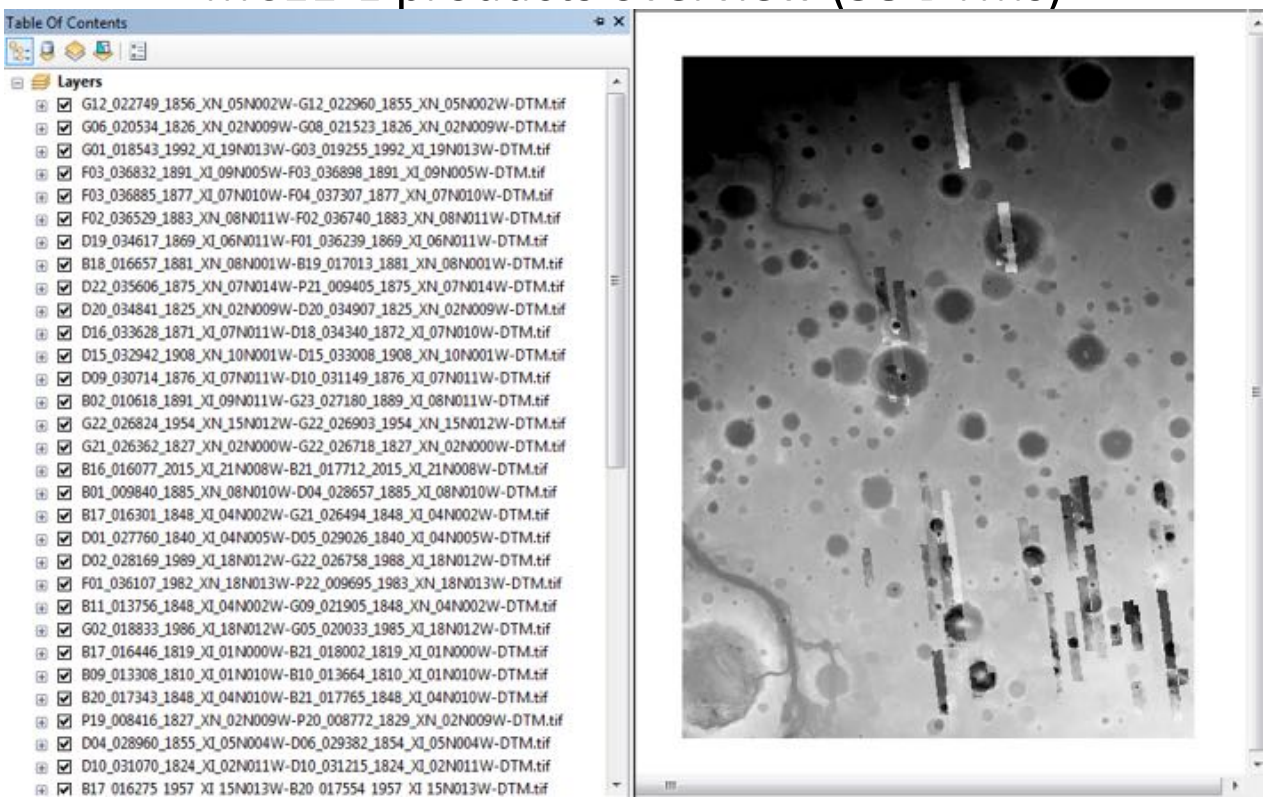


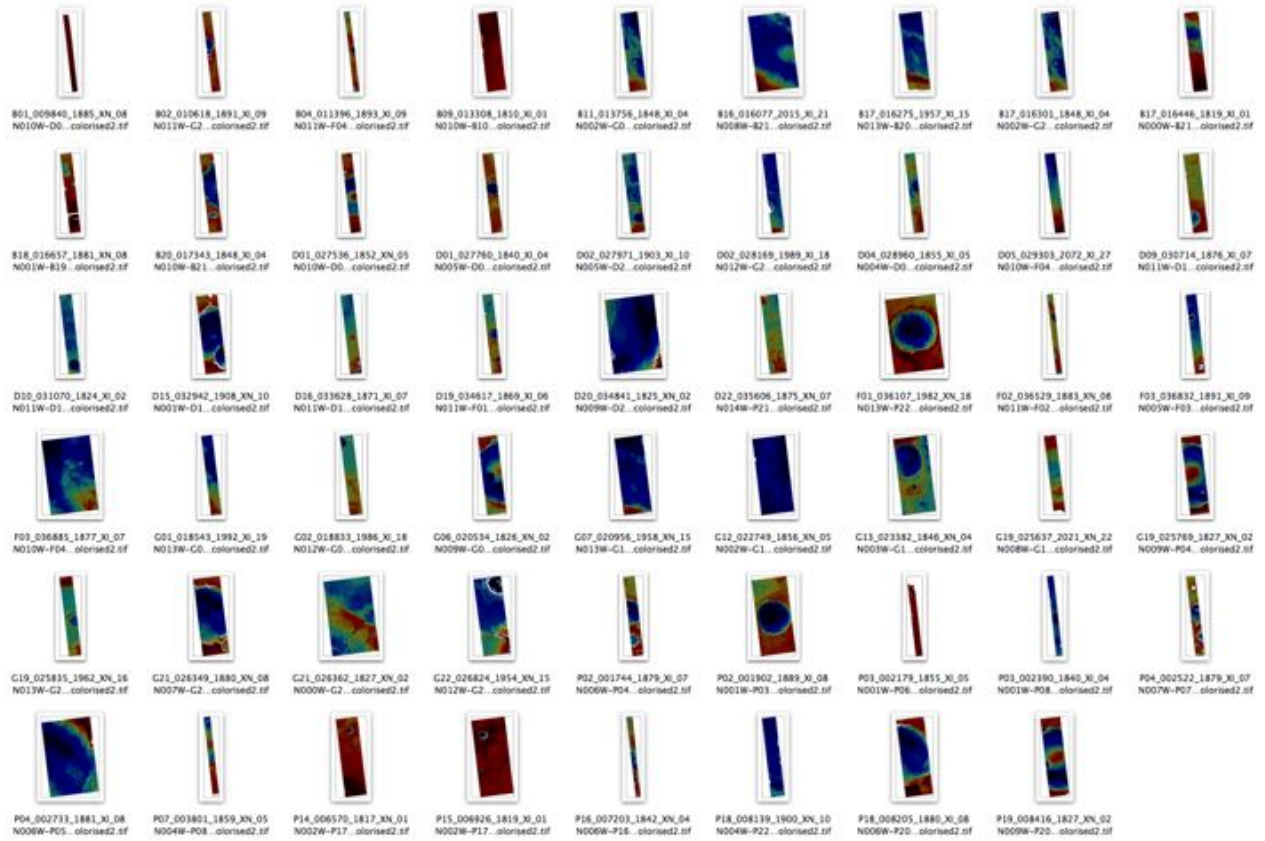
HiRISE DTM hill shaded image

j.muller@ucl.ac.uk



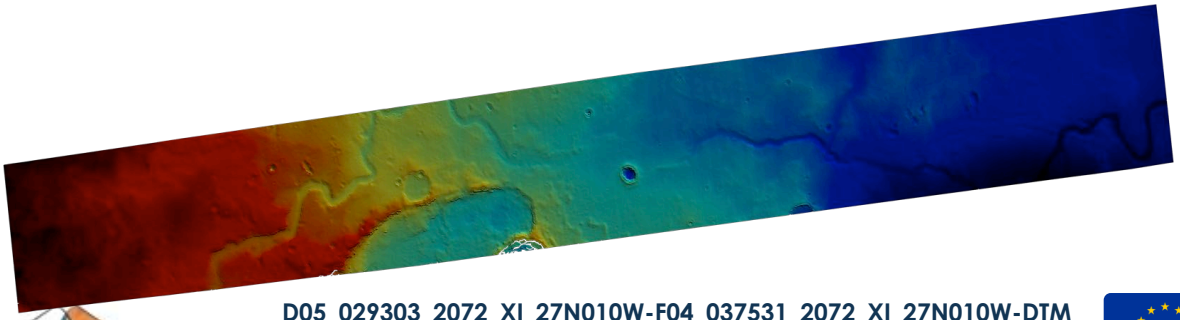
MC11-E products overview (58 DTMs)





Example of MC11-E products

D05_029303_2072_XI_27N010W-F04_037531_2072_XI_27N010W-ORI



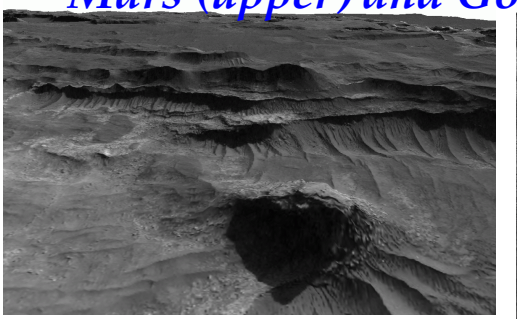
D05_029303_2072_XI_27N010W-F04_037531_2072_XI_27N010W-DTM

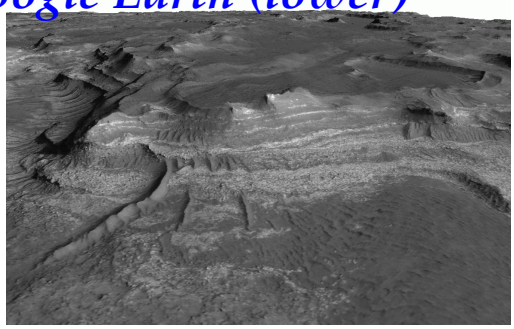
N.B. Colour LUT optimised for each DTM

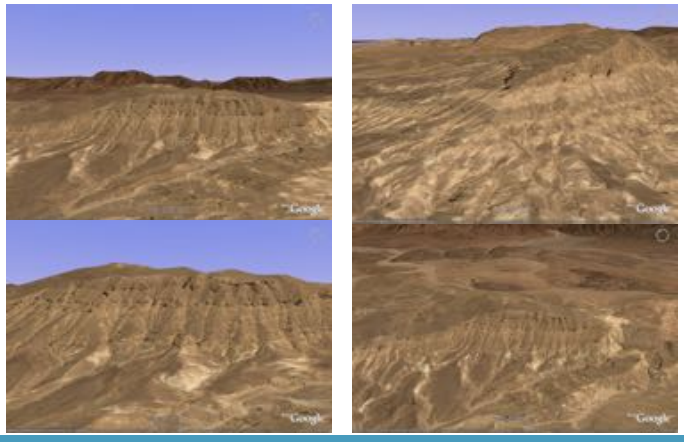
j.muller@ucl.ac.uk

Version: 08/06/16

How and what can we map from space? Mars (upper) and Google Earth (lower)



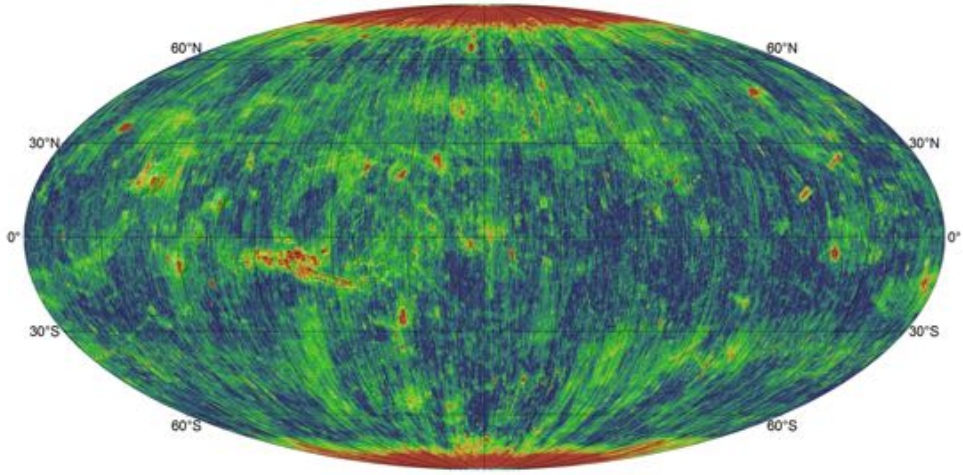




Perspective view of horizontal sedimentary beds in cliff faces over Mars - Eberswalde crater (upper) and Egypt (lower) at the SAME scale (courtesy of Sanjeev Gupta, Imperial College)

Overall Martian Surface coverage: MY12-31 (1976-2013) at ≤100m pixel IFoV. Out of 400,000 orbital images, ≈190,000 (UCL)

Restrictions to smaller numbers due to 45% HRSC DTM coverage



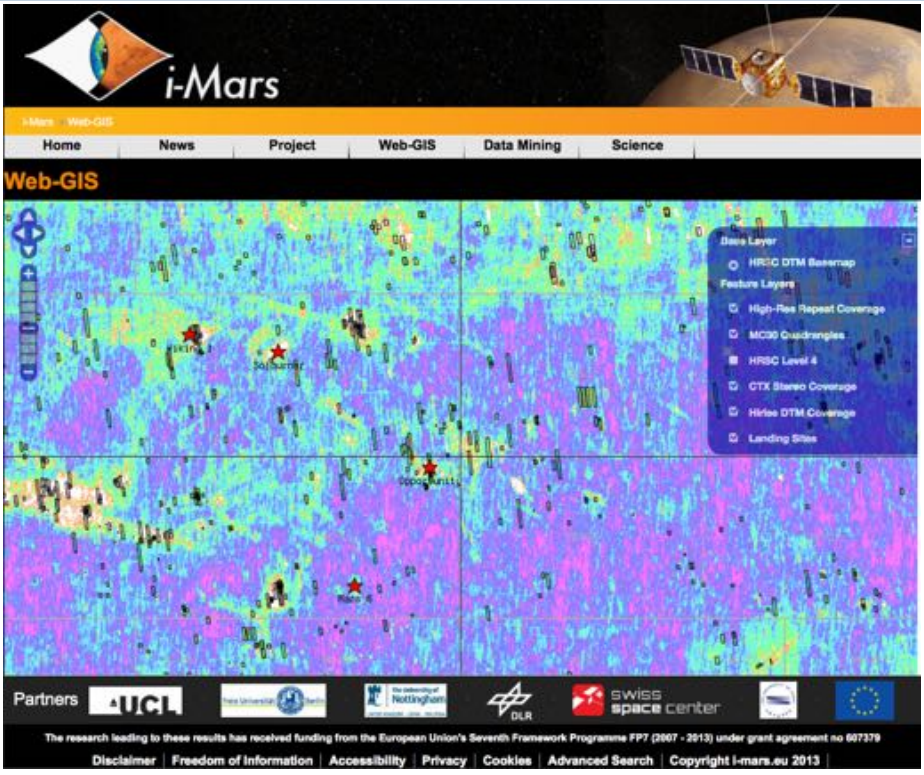
Martian Surface Coverage, Res<100m, MY12-31 (1976-2013)

Greyscale shaded map: NASA/MOLA science team

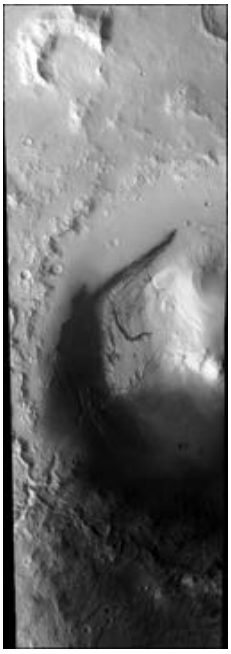
Repeat
High : >19
Low : 1

Sidiropoulos & Muller, PSS (2015)

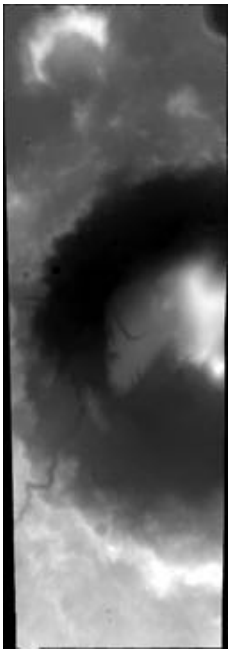
webGIS display: Repeat coverage map (UCL/FUB)



Fully Automated Auto-coregistration: Inputs



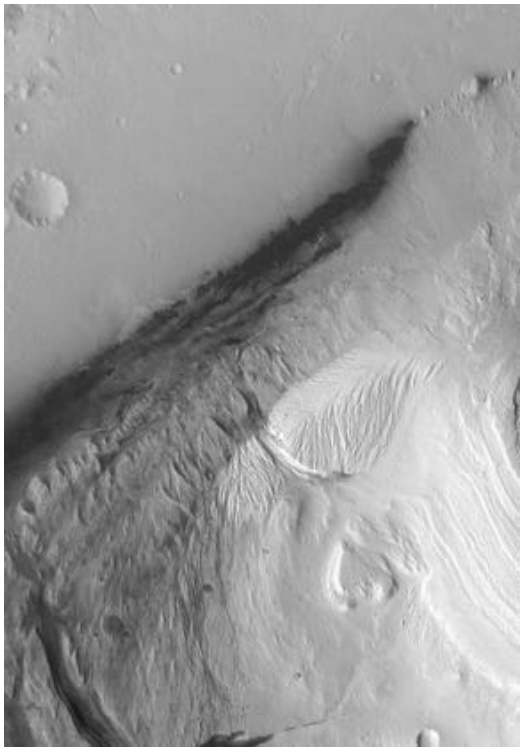
h4235_0001_ND4



h4235_0001_DT4

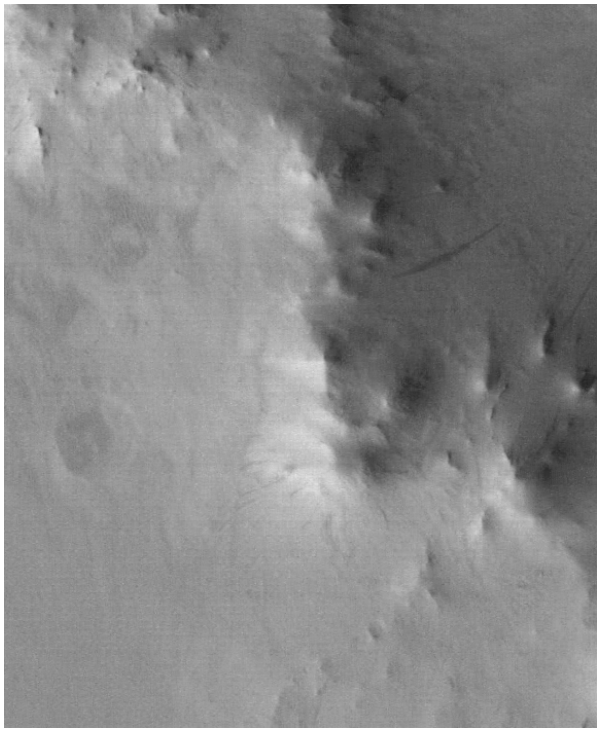
P06_003453_1752_XI_04S222W

Base Image: Corresponding h4235_0001_ND4 sub-image



Output: P06_003453_1752_XI_04S222W ORI (12.5m/pixel) - UCL

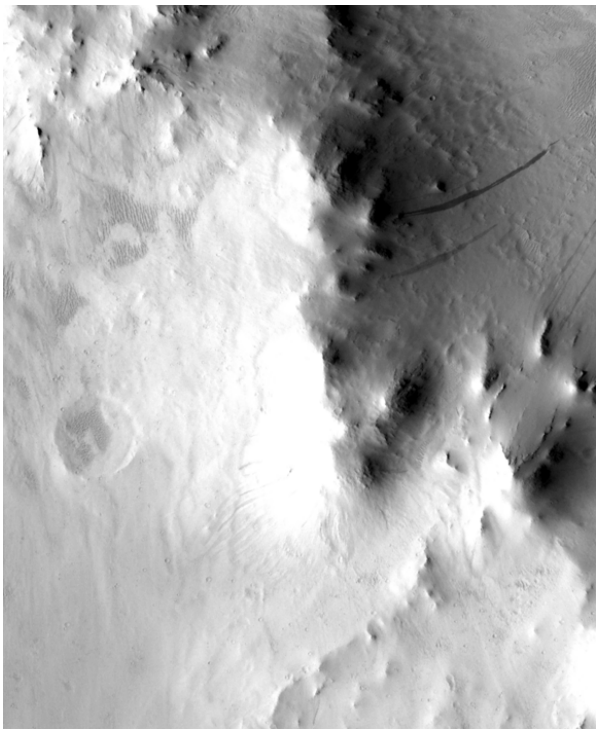
Example of changes between 2005-9 (CTX-HRSC)



Camera: HRSC
Res: 12.5 m/pixel
Date: 13 Aug 2005
Ls: 268

UCL

Example of changes between 2005-9 (CTX-HRSC)



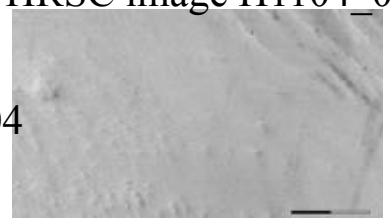
Camera: CTX
Res: 5.32 m/pixel
Date: 5 Feb 2009
Ls: 204

UCL

Change detection - preliminary results (much more to come…)

HRSC image H1104_0000

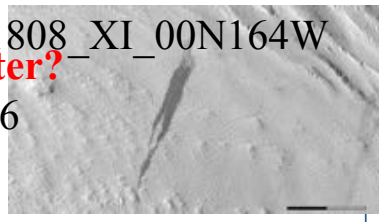
11/2004



CTX image
P02_001697_1808_XI_00N164W

Slope Streak – water?

12/2006



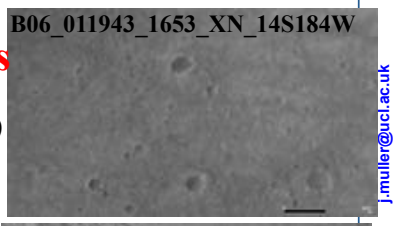
P12_005601_1653_XI_14S184W

10/2007

Dust Devil Tracks

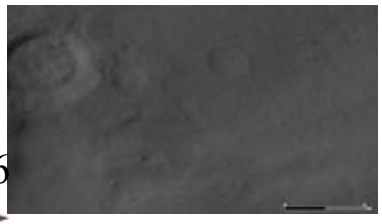
B06_011943_1653_XN_14S184W

2/2009



New Impact crater

5/2006



8/2009

HRSC image H2963_0000

CTX image
B12_014321_2095_XN_29N31

Key Elements (3) for training workshop from iMars

- Understand how to exploit GIS for extracting planetary science information from 3D images
- Explore the time history of Mars using the iMars webGIS
- Discover what new 3D imaging products are available from CTX and HRSC
- Explore the landscape using super-resolution imagery (from 5-12.5cm/pixel)
- Perform 3D measurements of geological features to learn how 3D imaging products can be employed to explore a landscape

i-Mars.eu

Thanks to the following

- **The UCL-MSSL backroom team:**
  Samantha Babister, Rosalind Medland, Suzanne Winter, Gill Watson, Panagiotis Sidiropoulos, Yu Tao, Kiky Alfiah Putri, Si-Ting Xiong, Ed Malina, Lang Feng, Nick Smith, Sue Ford
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  Joanna Fabbri, Steve Miller (UCL)
- **The trainers' team:**
  Björn Schreiner, Federico Cantini, Jacqueline Campbell, Joel Davis, Jennifer Harris, Jessica Wardlaw, Kiky Putri, Konrad Wilner, Lida Fanara, Michele Giordano, Peter Fawdon, Peter Grindrod, Panagiotis Sidiropoulos, Rob Barnes, Ralf Steikert, Steve Banham, Yu Tao