ESWT Torino, 2019-06-05

PRo3D Rendering & 3D Analysis tool for instrument cooperation

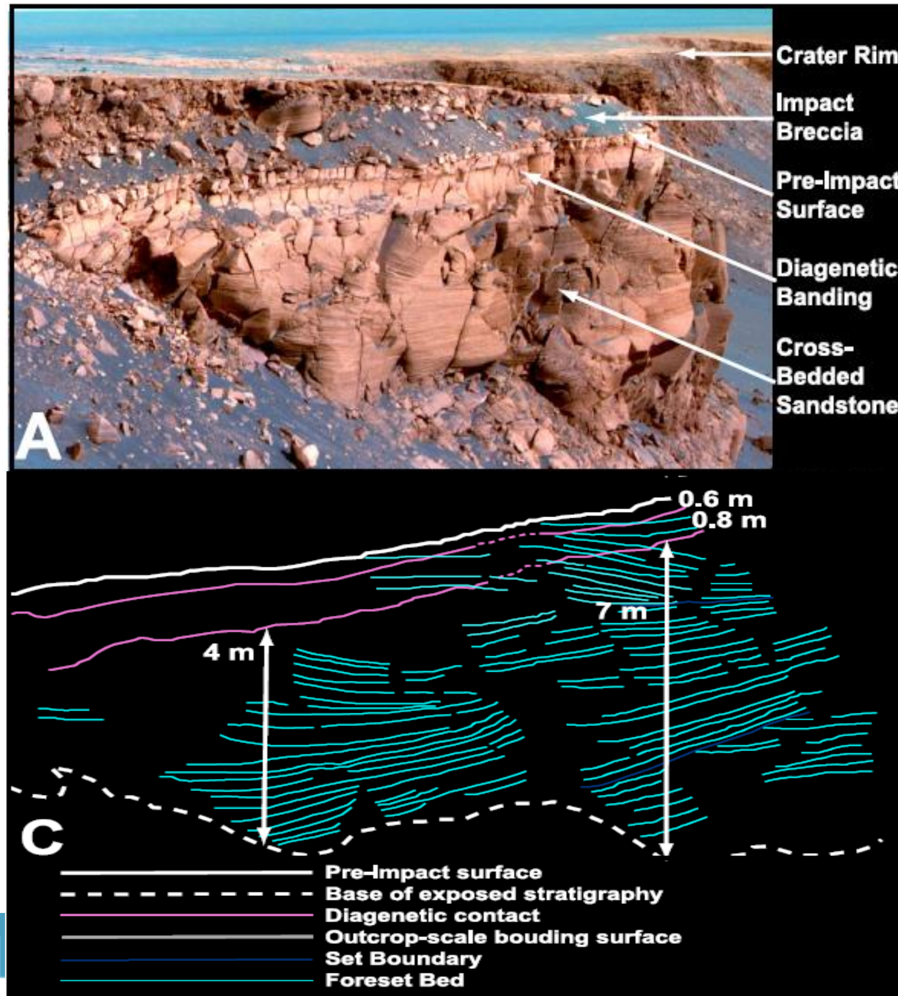
Thomas Ortner(2), **Gerhard Paar(1)**, Christoph Traxler(2), Piluca Caballo-Perucha(1), Rob Barnes(3), Sanjeev Gupta(3), Kevin Kearney(4), Fabian Schindler (5)

(1) JOANNEUM RESEARCH; ExoMars PanCam & CLUPI Co-I, Mars 2020 Mastcam-Z Co-I
(2) VRVis, (3) Imperial College London, (4) Natural History Museum Vienna, (5) EOX IT Services

Purpose of (3D) Vision on Mars

- Context
  - What is interesting ?
  - Where to go next ?
- Navigation
  - Where am I ?
  - Which path to take ?
  - Am I moving correctly ?
  - Any hazards ?
- Inspection
  - Am I doing well ?
- **Science….**
- **& Collaboration**

Imperial College London



Targets of Rover Imaging: Customers / Functions / Products

- Mission Clients
  - Rover Driving Team to plan
  - **Scientists to plan**
  - **Scientists to analyze**
- The Public
  - For education
  - As tax payer
  - For science

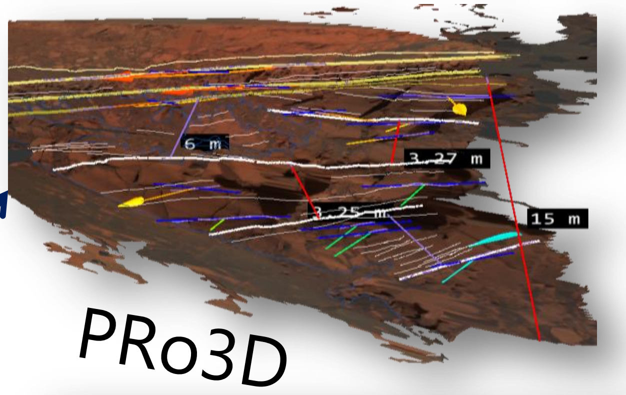
- 3D Mapping
  - On-board path planning & hazard avoidance
  - **On-ground for tactical & strategic planning**
- Navigation
  - On-board visual odometry
  - On-ground absolute localization
- Visualization
  - Planning & understanding operations
  - **Planning & understanding science**
  - **Context for instruments**

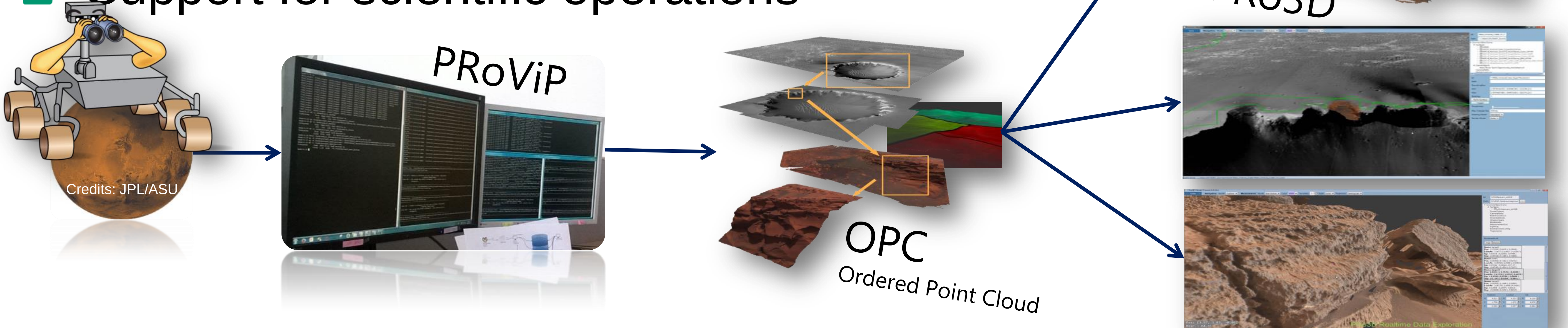
Atmosphere Analyses

Multispectral Analyses

Morphology

- PRoViP: Batch Stereo / 3D Vision Processing
  - DTM, Panoramas, other 3D data products from PanCam/NavCam/LocCam
- PRo3D: Interactive Real-Time Rendering
  - Huge multi-scale 3D data
  - Support for scientific operations

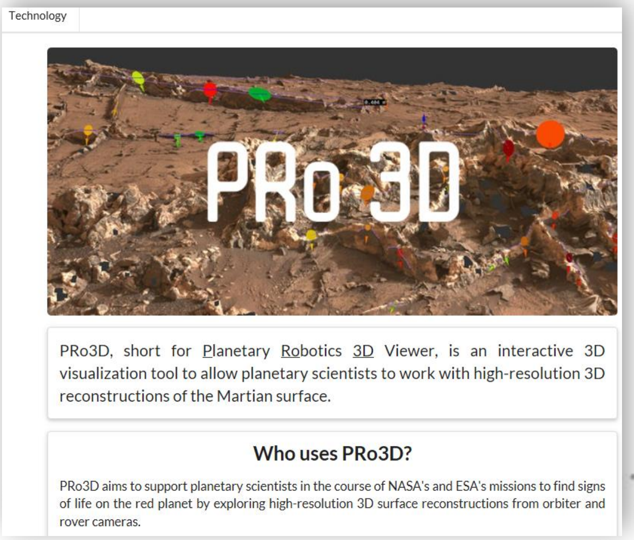




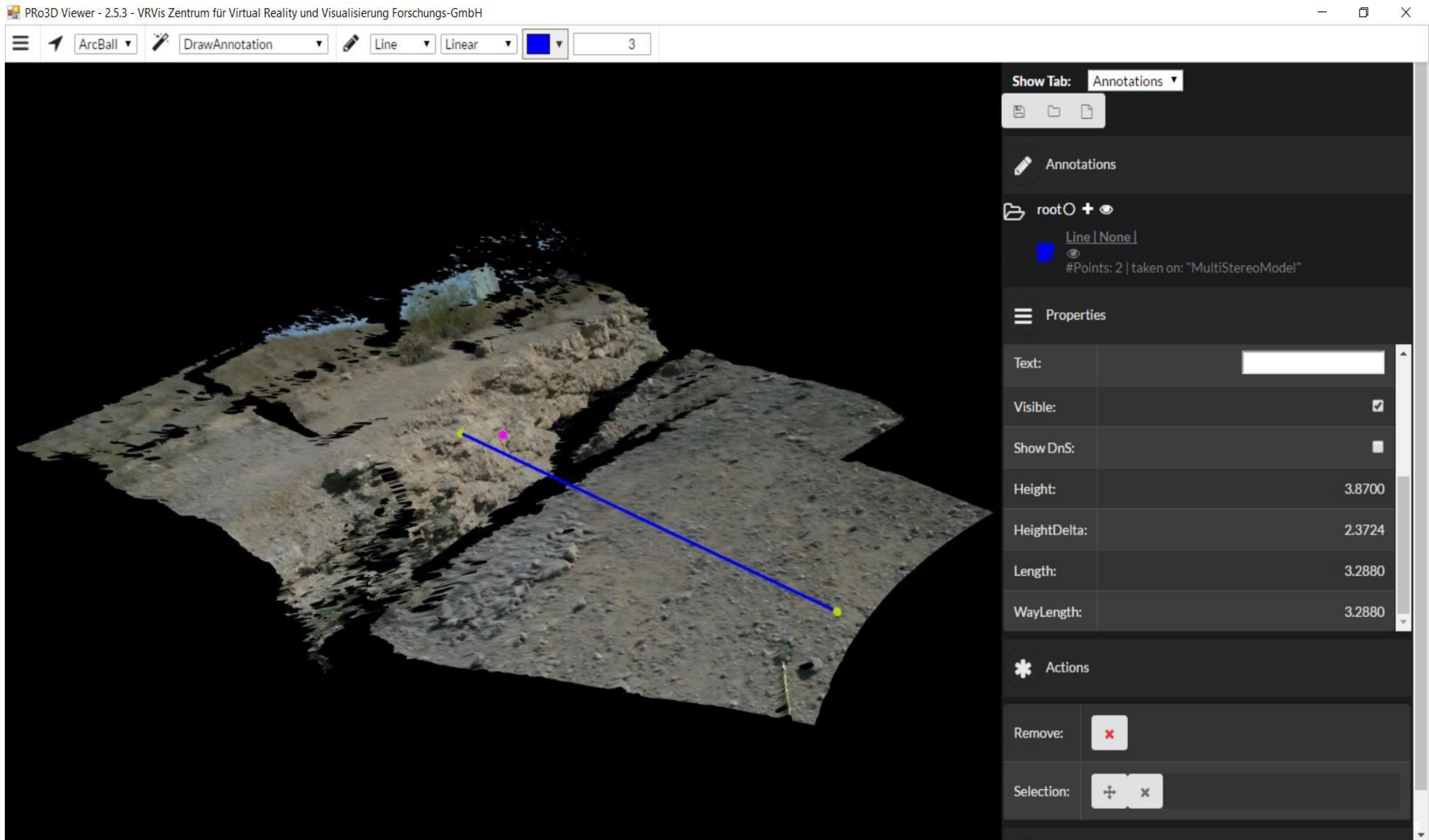
Planetary 3D Vision – PRo3D Viewer

Planetary Robotics 3D Viewer (PRo3D) developed by JR long-term partner [VRVis](#) is an **interactive real-time renderer to explore 3D vision products**.

http://pro3d.space/



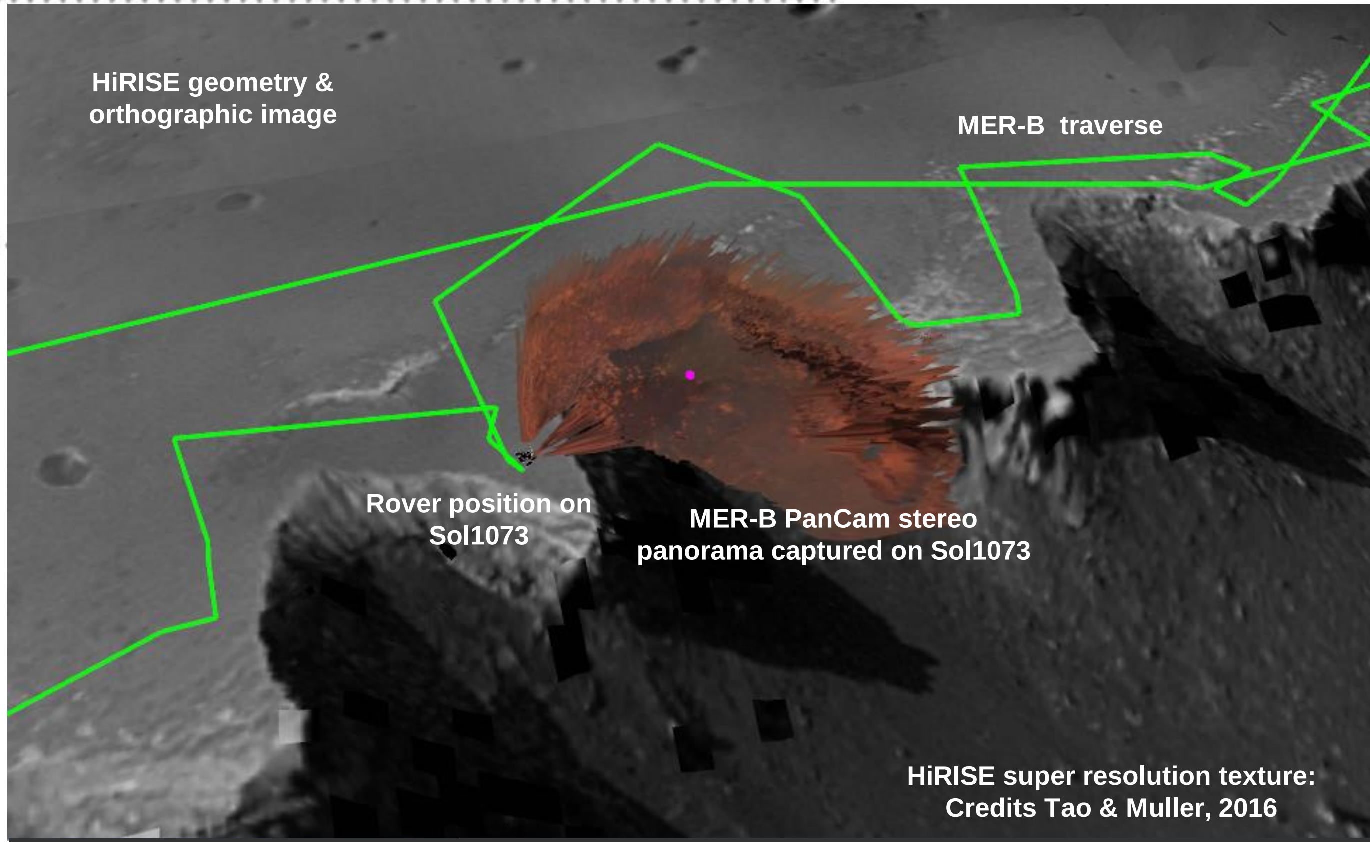
PRo3D standalone version (here: annotation mode)

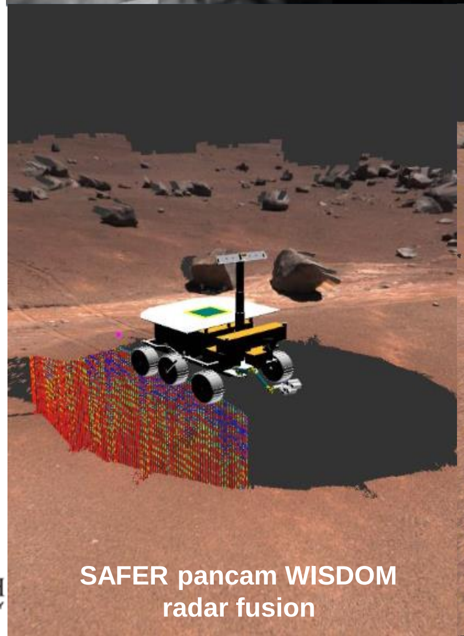


PRo3D Features I

- interactive rendering of **multi-scale 3D surfaces** in **different render modes** (i.e. solid, wireframe)
- **efficient large-context navigation** in the 3D scene using explore, free fly or orbital mode for overall scene understanding
- Ordered Point Cloud format* (OPC) containing 3D data as **real Cartesian coordinates** (x/y/z) in **different pre-processed resolutions** to facilitate **position and distance dependent level-of-detail rendering**
- visualization & navigation of **huge datasets** („no limits“ due to out-of-core technique)
- **visual fusion** of multi-sensor and multi-scale data
- **visualization and manipulation** of other data, such as **vrml objects**, **trajectories**, **3D point lists** and sub-suface **radar scans**

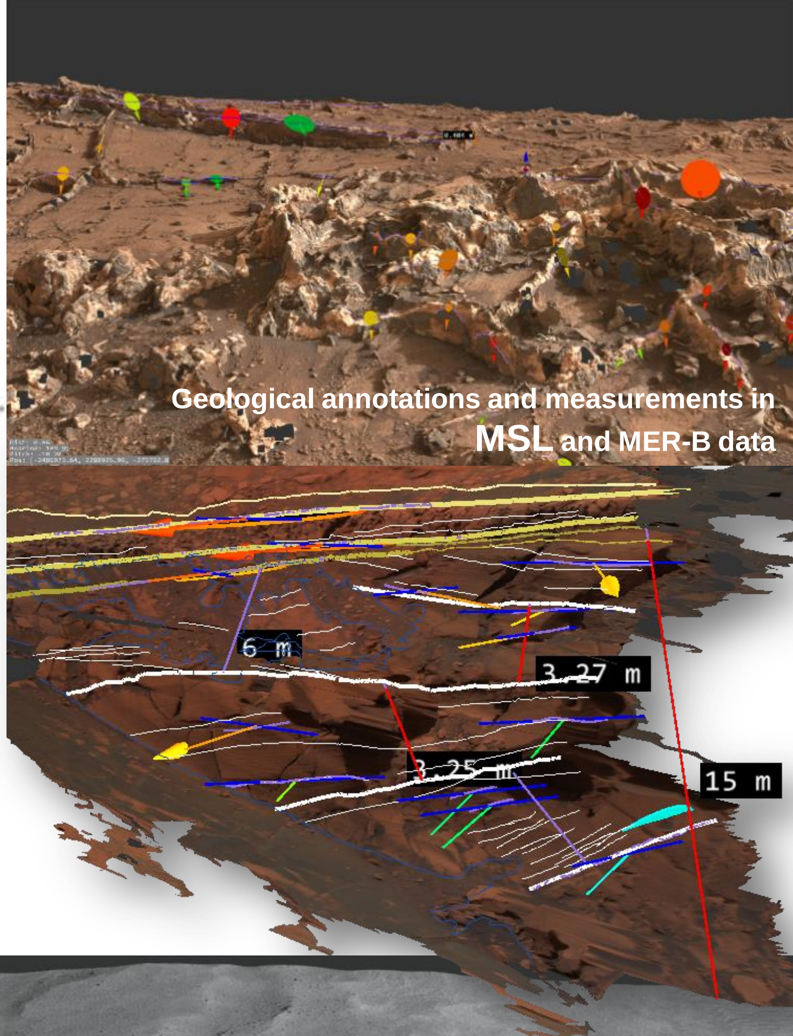
*OPC format developed by VRVis & JR



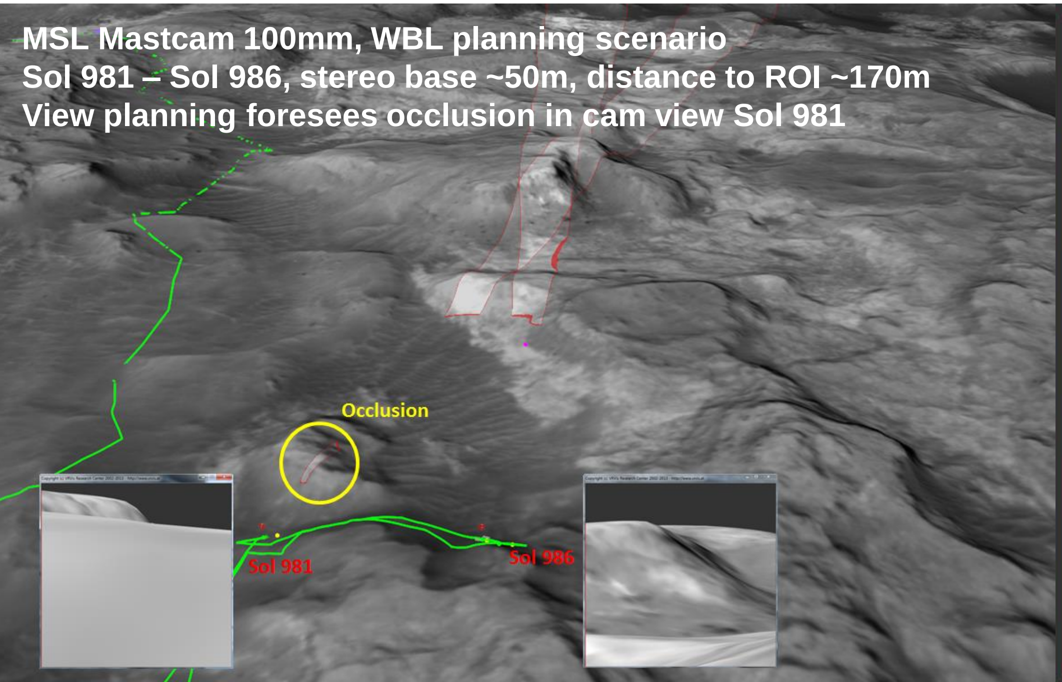


PRo3D Features II

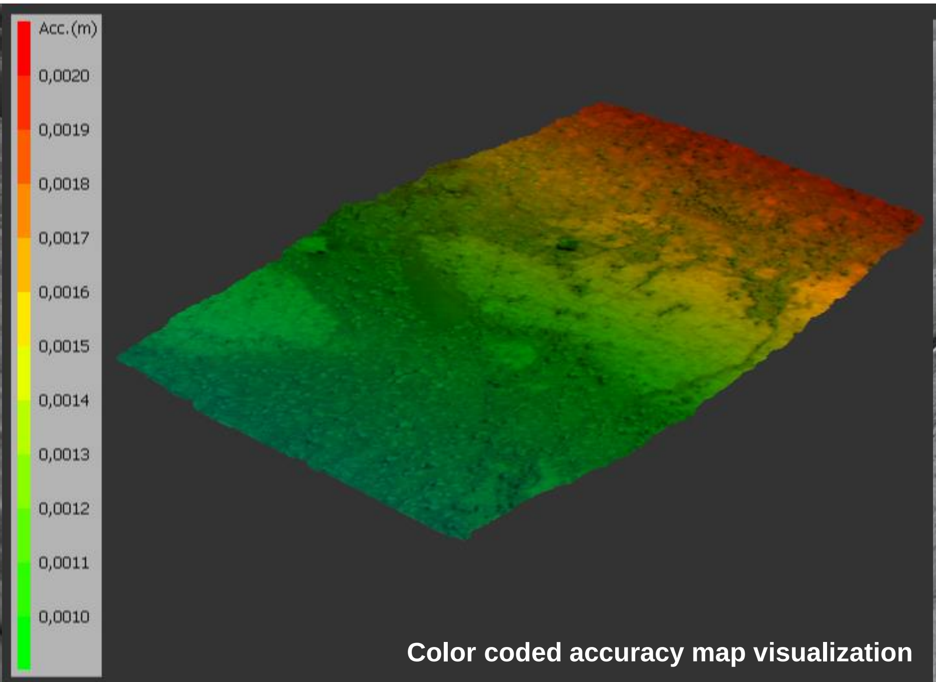
- handling of **multiple textures** and **maps** (DEM by-products) for 3D geometry complementation
- **measurement tools** for exact **geological assessment** of the surface
- **annotation** of surfaces and other scene elements
- **view planning** and **simulated view** functionality to simulate various instruments' field of view
- **user interactive transformations** of all supported data types
- **multi user** handling / data exchange



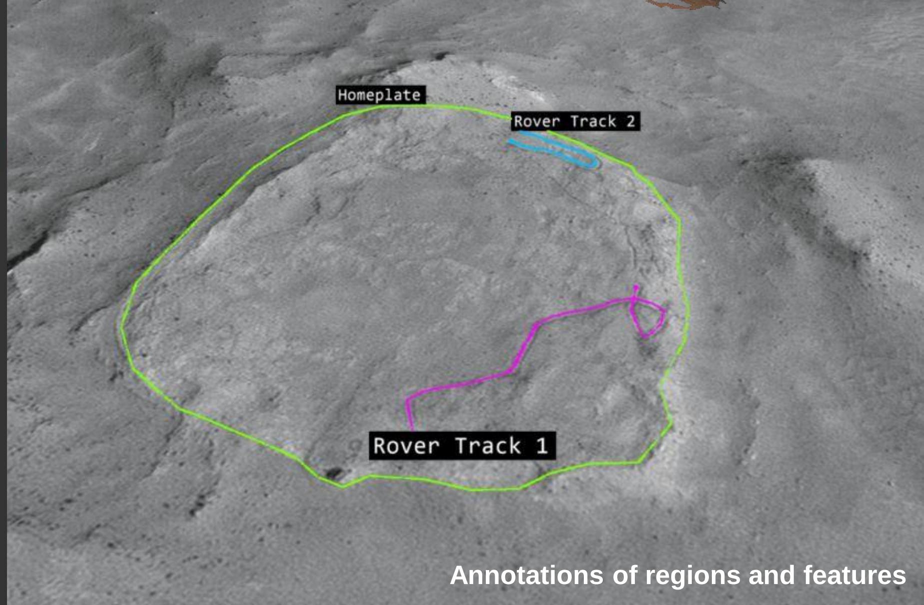
Geological annotations and measurements in MSL and MER-B data



MSL Mastcam 100mm, WBL planning scenario
Sol 981 – Sol 986, stereo base ~50m, distance to ROI ~170m
View planning foresees occlusion in cam view Sol 981

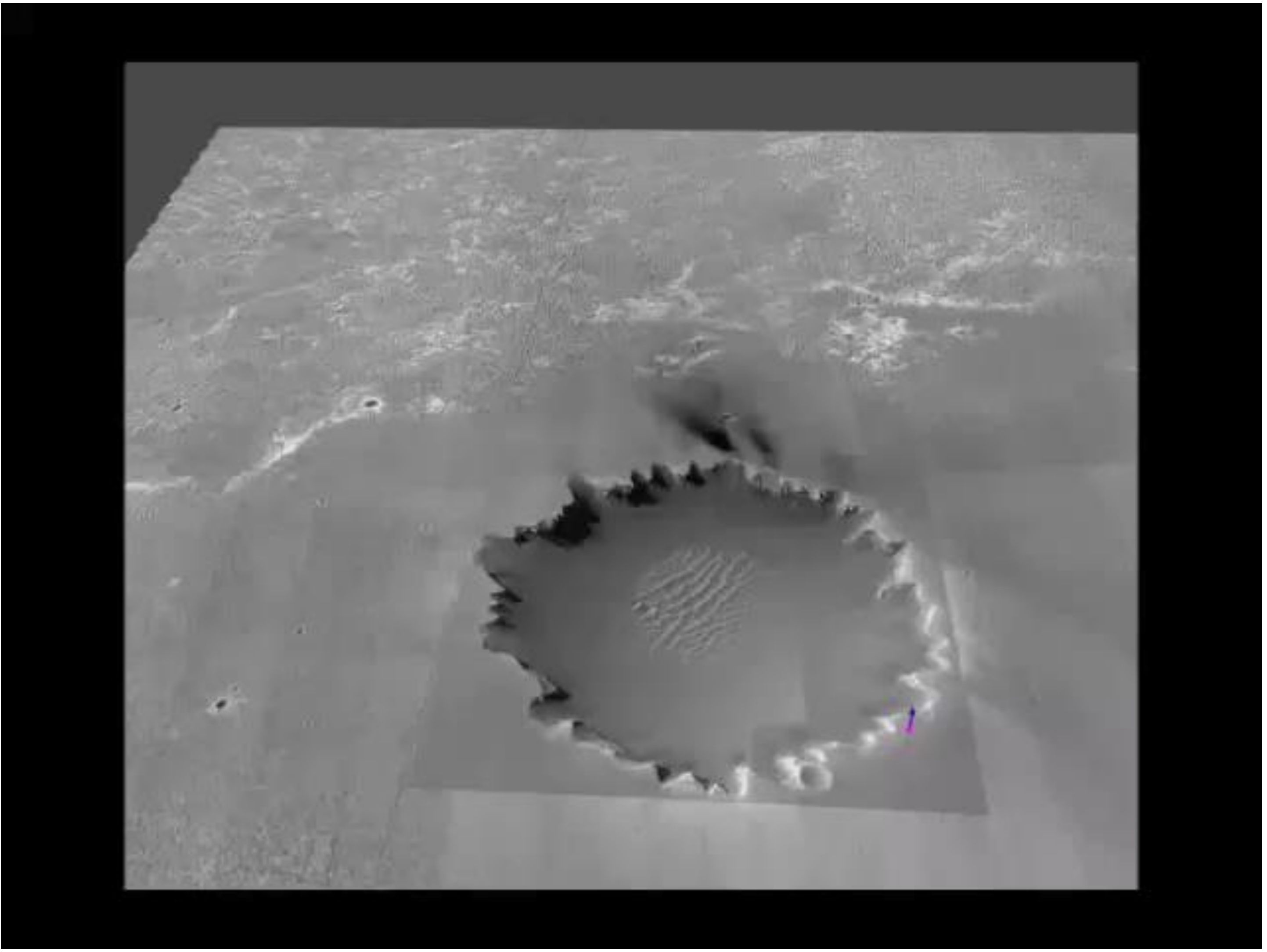


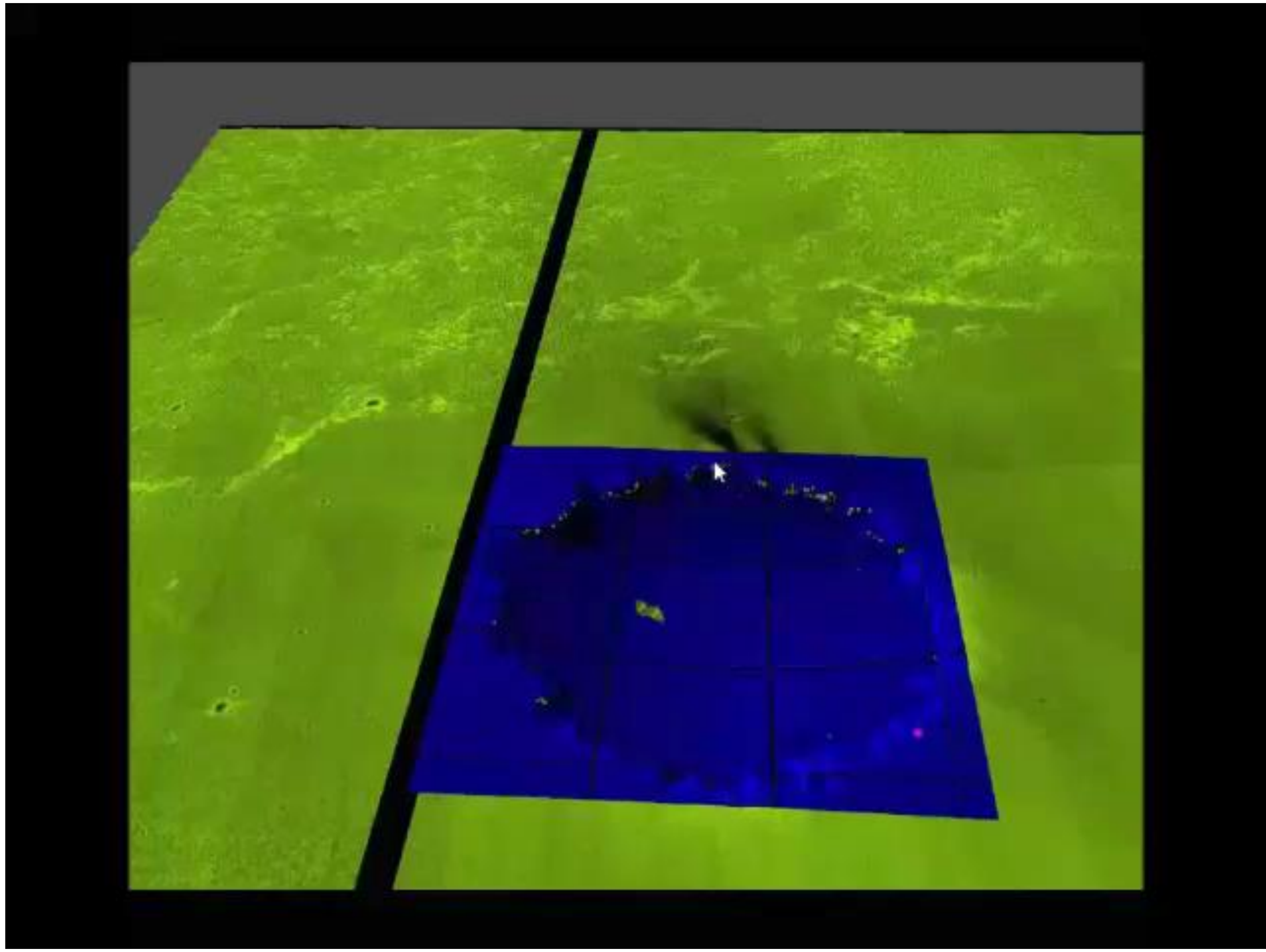
Color coded accuracy map visualization



Annotations of regions and features

Supporting Data Fusion and Levels of Detail





Interaction in PRo3D: Geological Annotations

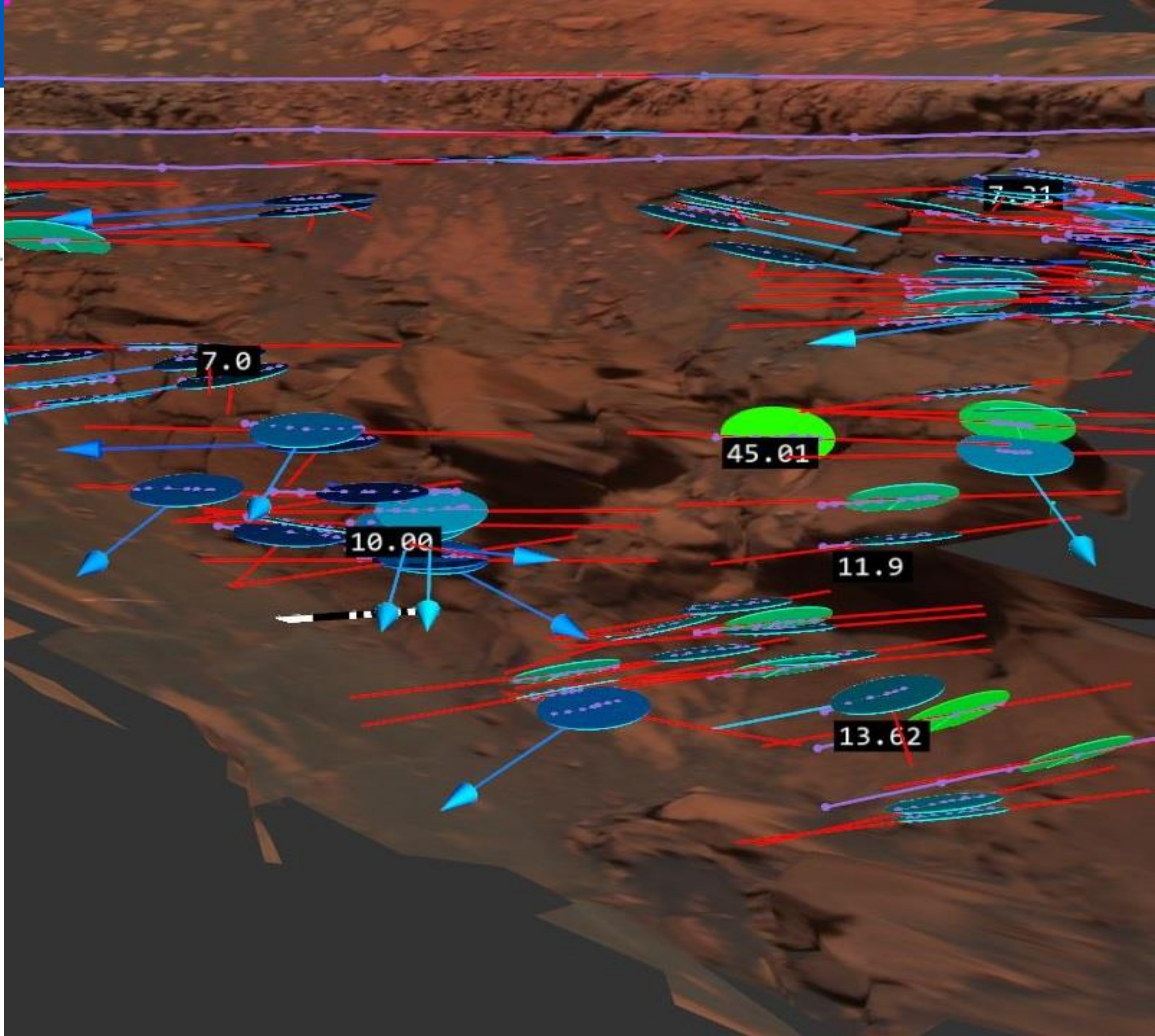
Geometry

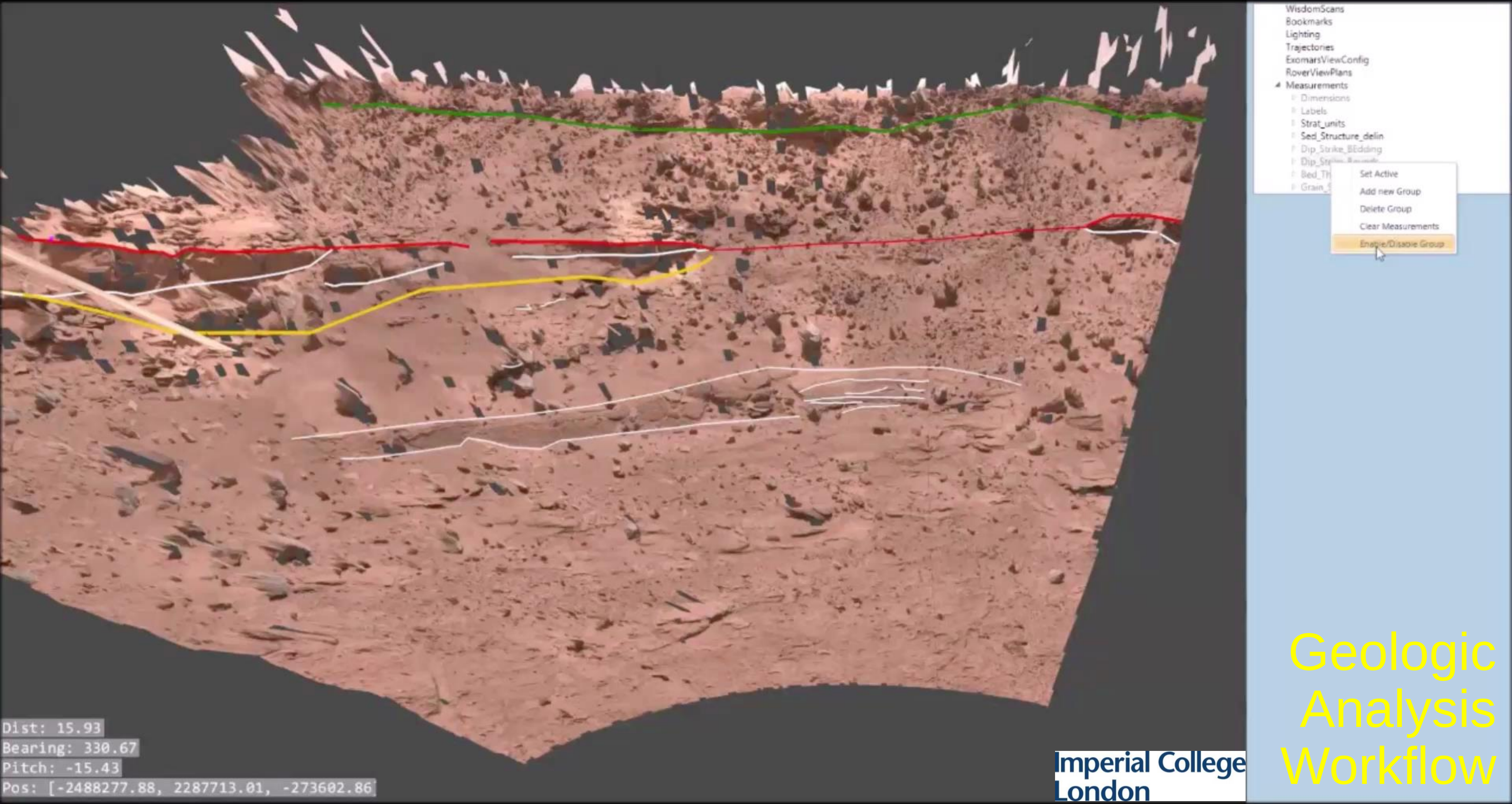
Style

Text

Projection

Derived Values

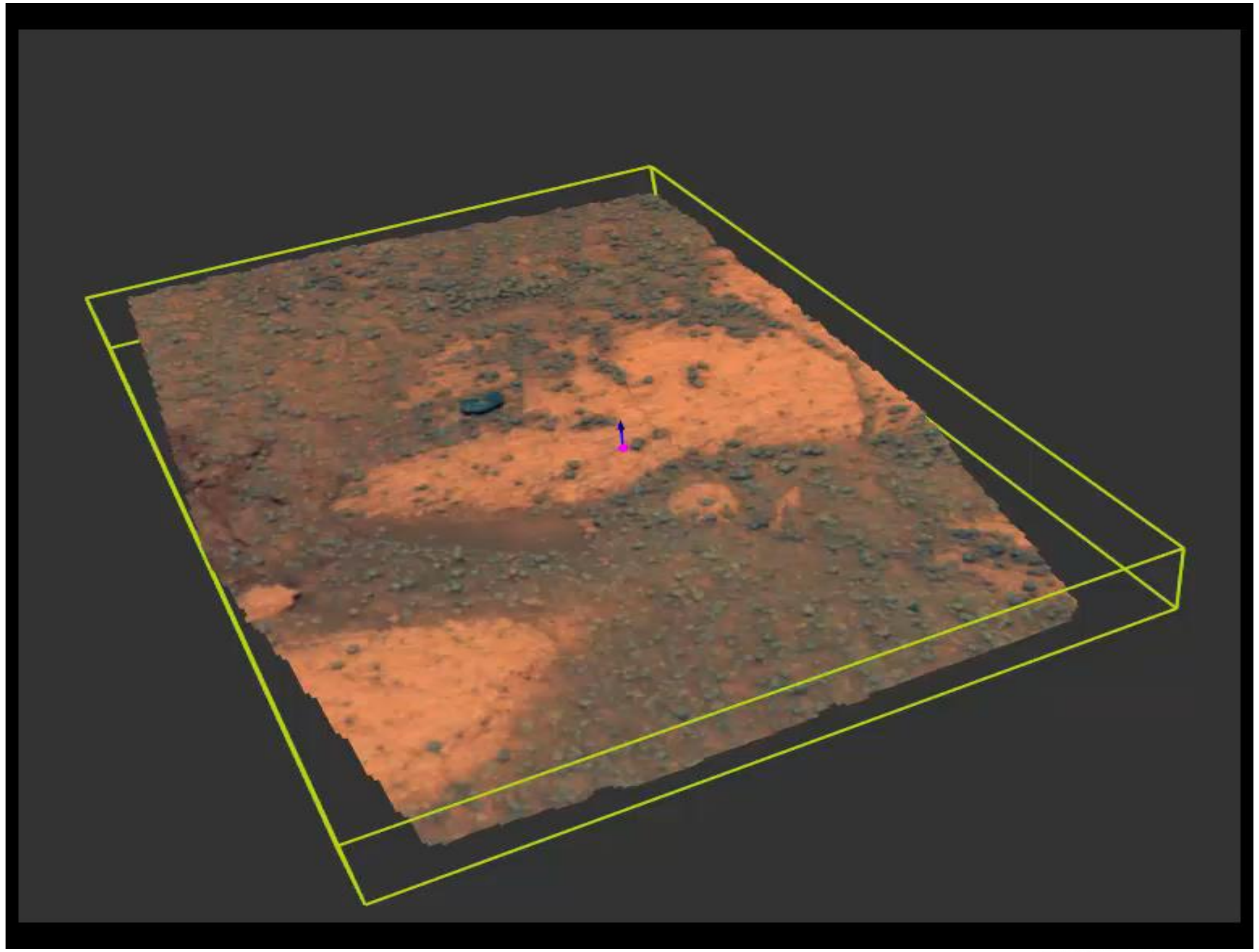


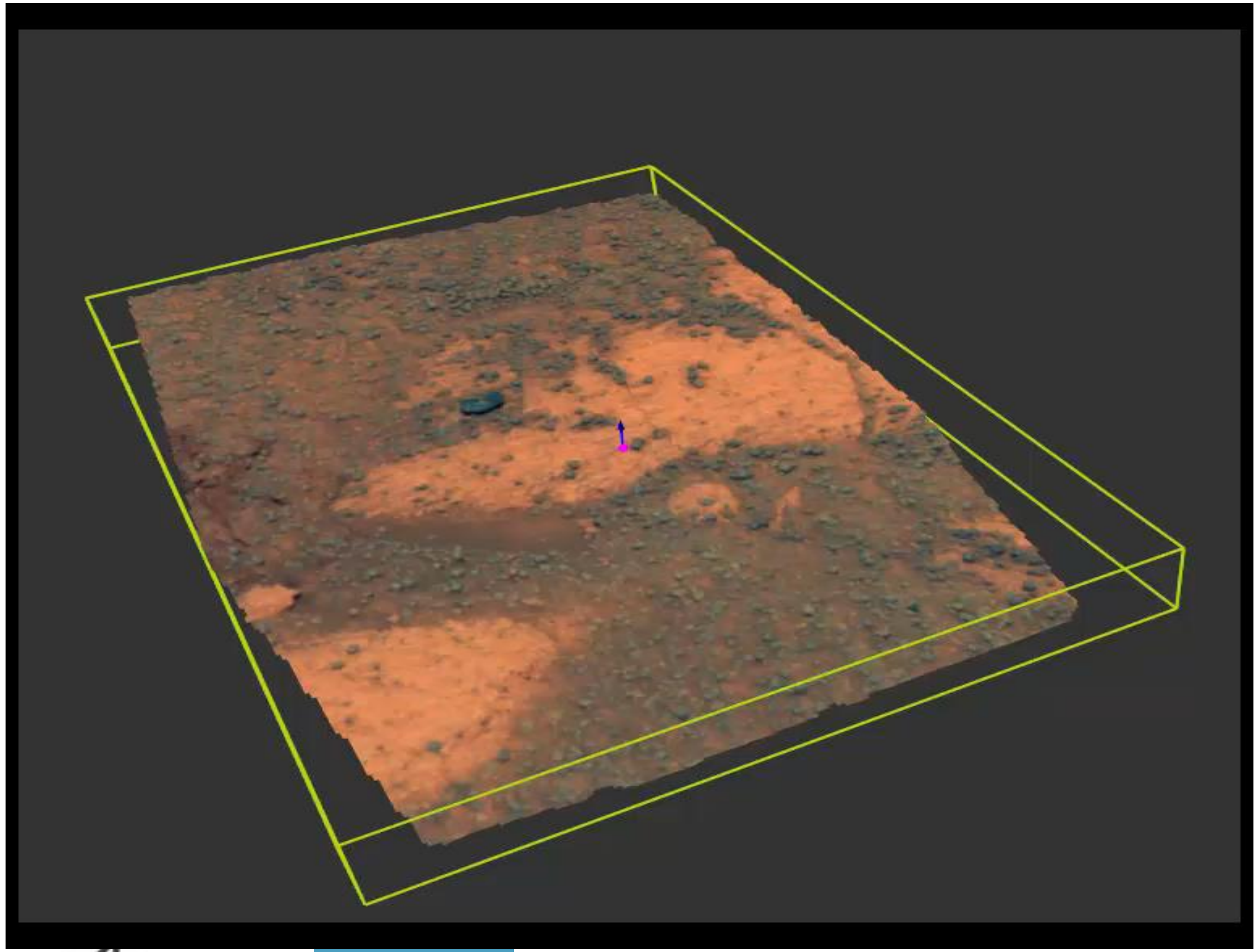

WisdomScans
Bookmarks
Lighting
Trajectories
ExomarsViewConfig
RoverViewPlans
Measurements
Dimensions
Labels
Strat_units
Sed_Structure_delin
Dip_Strike_BEdding
Set Active
Add new Group
Delete Group
Clear Measurements
Enable/Disable Group
Dist: 15.93
Bearing: 330.67
Pitch: -15.43
Pos: [-2488277.88, 2287713.01, -273602.86
Imperial College London
Geologic Analysis Workflow

Work in Progress:
Multiple Layers Data Structures & Rendering

Multiple Textures

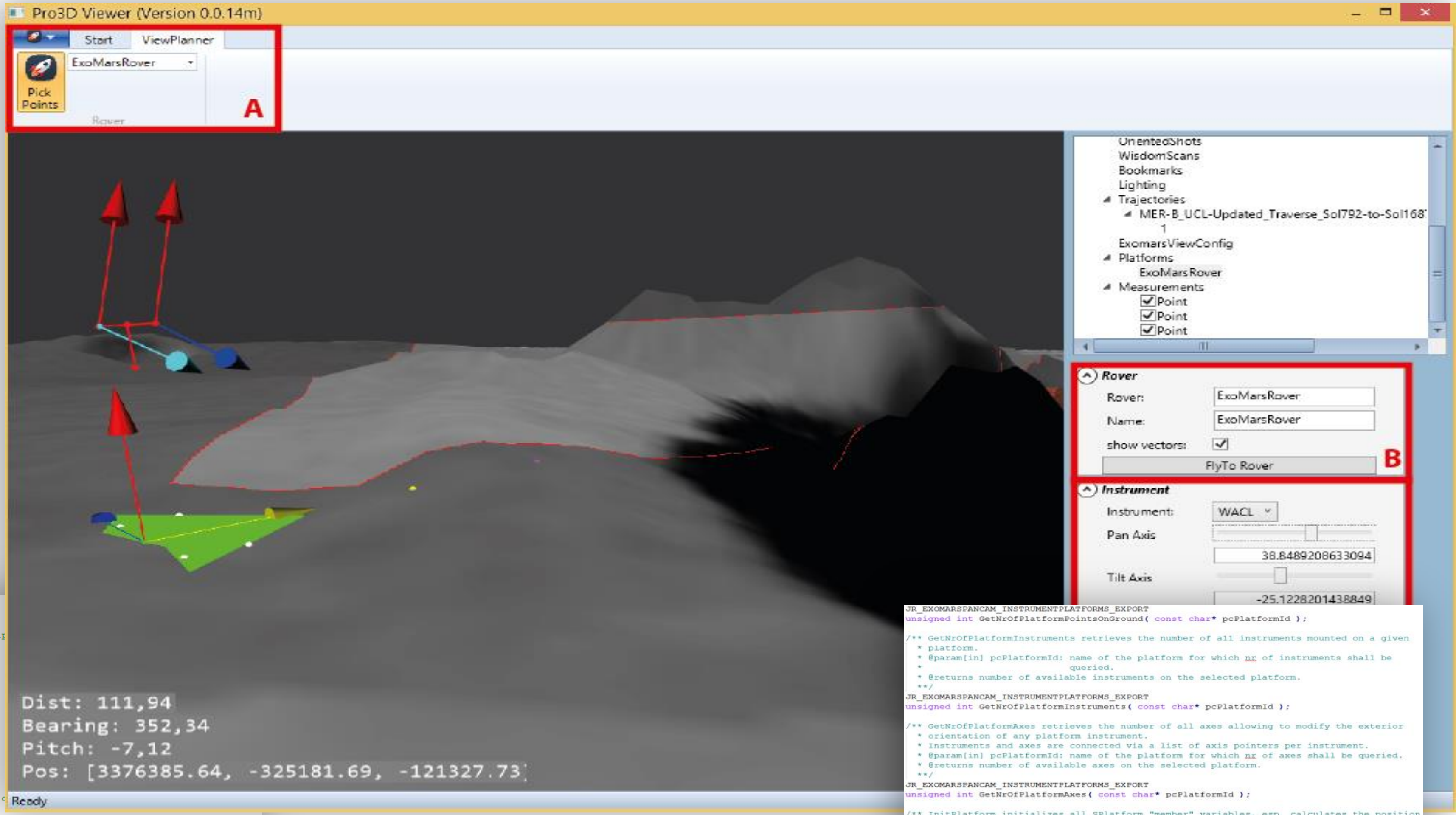
Attribute Layer





InstrumentPlatforms.dll – PRo3D Robotic Interface

- **Geometric model & FoV / footprint of an instrument-carrying platform (eg. rover)**
  - **WISDOM**
  - **Drill & CLUPI**
  - **ISEM, TSPP, ….**
- **Moving camera**
- **Generic interface**
  - **Allows defining mirror views as additional instrument option**
- **Platform geometry and instrument characteristics are defined in xml file**
- **Interface: C functions and structs (can be used with C++, C#, Python, …)**

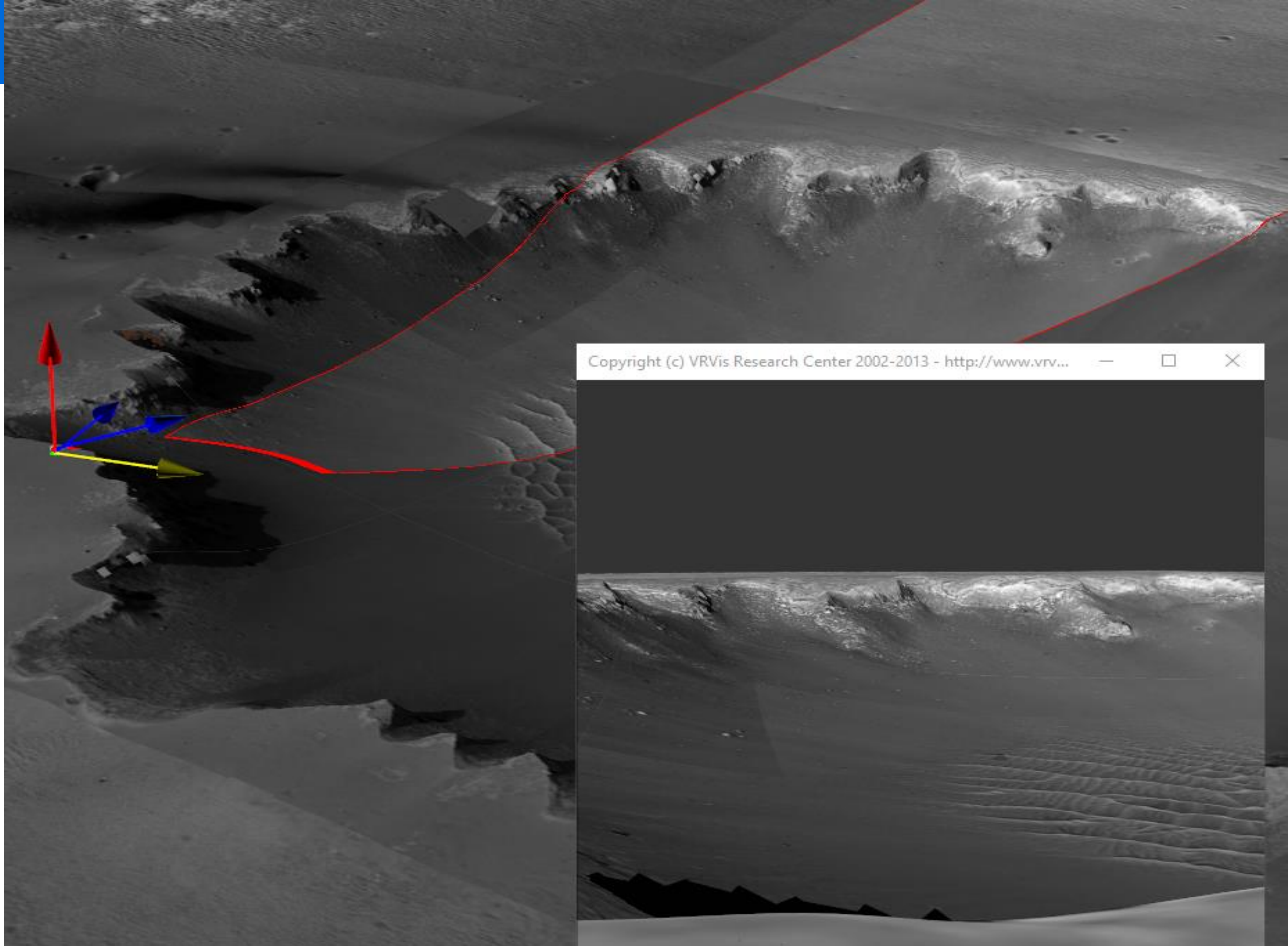



```xml
<!-- Left Wide Angle Camera (AUPE), as calibrated during SAFER field trial in Chile -->
<WACL_AUPE>
    <!-- AUPE WAC camera specifications:
    Sensor Resolution: 2452 x 2056. Pixel size: 3.54um. Sensor size: 8.45x7.09mm. focal length: 12mm. ap
    39°x33°. -->
    <Intrinsics>
        <!-- image dimensions in px (PRo3D: for correct image size rendering) -->
        <Resolution>1024, 1024</Resolution><!-- binning! -->
        <ZoomStep>
            <!-- focal length in mm (PRo3D: as user information) -->
            <FocalLength>12</FocalLength>
            <Filter>
                <!-- filter id -->
                <FilterID>all</FilterID>
                <!-- focal lengths per pixel (PRo3D: optional/not used) -->
                <FocalLengthPx>1382.911, 1382.911</FocalLengthPx>
                <!-- angle (gon) for camera horizontal FoV-->
                <HorizontalFoV>37.000</HorizontalFoV> <!-- adapted with respect to reduced sensor size
                <!-- angle (gon) for camera vertical FoV-->
                <VerticalFoV>37.000</VerticalFoV> <!-- adapted with respect to reduced sensor size due to binning & cut offs for AUPE -->
                <!-- pixel coordinates of the principal point -->
                <PrinciplePoint>512, 512</PrinciplePoint>
                <GeometricDistortion>
                    <Method></Method>
                    <!-- tangential & radial distortion coefficients -->
                    <Coefficients></Coefficients>
                </GeometricDistortion>
            </Filter>
        </ZoomStep>
    </Intrinsics>
    <RelativeOrientation>
        <ReferenceFrame>WACL_AUPE</ReferenceFrame>
        <!-- 3D camera coordinates (meters) -->
        <XYZPosition>0.000, 0.000, 0.000</XYZPosition>
        <!-- 3D components of the camera up vector -->
        <CamUpVector>0.000, 0.000, 1.000</CamUpVector>
        <!-- 3D components of the camera look at vector -->
        <CamLookAtVector>1.000, 0.000, 0.000</CamLookAtVector>
        <BoundingBox>
```

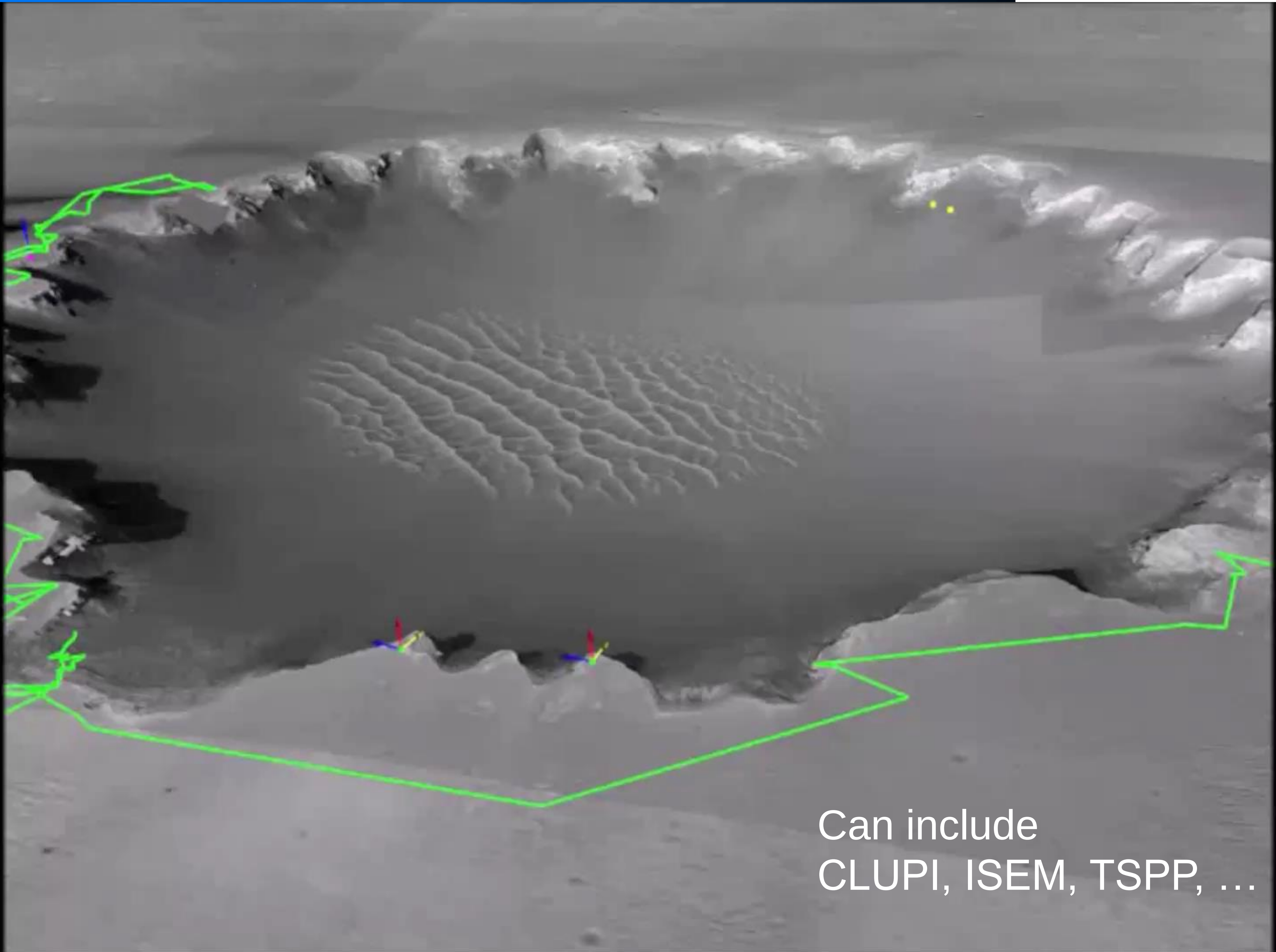
```c
JR_EXOMARSPANCAM_INSTRUMENTPLATFORMS_EXPORT
unsigned int GetNrOfPlatformPointsOnGround( const char* pcPlatformId );

/** GetNrOfPlatformInstruments retrieves the number of all instruments mounted on a given
  * platform.
  * @param[in] pcPlatformId: name of the platform for which nr of instruments shall be
  *                          queried.
  * @returns number of available instruments on the selected platform.
  **/
JR_EXOMARSPANCAM_INSTRUMENTPLATFORMS_EXPORT
unsigned int GetNrOfPlatformInstruments( const char* pcPlatformId );

/** GetNrOfPlatformAxes retrieves the number of all axes allowing to modify the exterior
  * orientation of any platform instrument.
  * Instruments and axes are connected via a list of axis pointers per instrument.
  * @param[in] pcPlatformId: name of the platform for which nr of axes shall be queried.
  * @returns number of available axes on the selected platform.
  **/
JR_EXOMARSPANCAM_INSTRUMENTPLATFORMS_EXPORT
unsigned int GetNrOfPlatformAxes( const char* pcPlatformId );

/** InitPlatform initializes all SPlatform "member" variables, esp. calculates the position
  * and orientation of all platform instruments according to the given initial position and
  * orientation of the platform in Ground Reference Frame.
  * Arrays in poPlatform must be pre-allocated!
  * @param[in] nNrOfPlatformPointsOnGround: max. number of points on ground which
  *                                         poPlatform can contain.
  * @param[in] nNrOfPlatformInstruments: max. number of instruments which poPlatform can
  *                                      contain.
  * @param[in] nNrOfPlatformAxes: max. number of axes which poPlatform can contain.
  * @param[out] poPlatform: platform including all related data to be initialized.
  * @returns error code.
  **/
JR_EXOMARSPANCAM_INSTRUMENTPLATFORMS_EXPORT
int InitPlatform( SPlatform* poPlatform, unsigned int nNrOfPlatformPointsOnGround,
                  unsigned int nNrOfPlatformInstruments, unsigned int nNrOfPlatformAxes );

/** UpdatePlatform updates all SPlatform "member" variables - esp. the position and
  * orientation of all platform instruments - according to the given position and
  * orientation of the platform. It also updates intrinsics of instruments with
  * zooming capability according to the currently set focal length.
  * @param[out] poPlatform: platform including all related data to be updated.
  * @returns error code.
  **/
JR_EXOMARSPANCAM_INSTRUMENTPLATFORMS_EXPORT int UpdatePlatform( SPlatform* poPlatform );
```

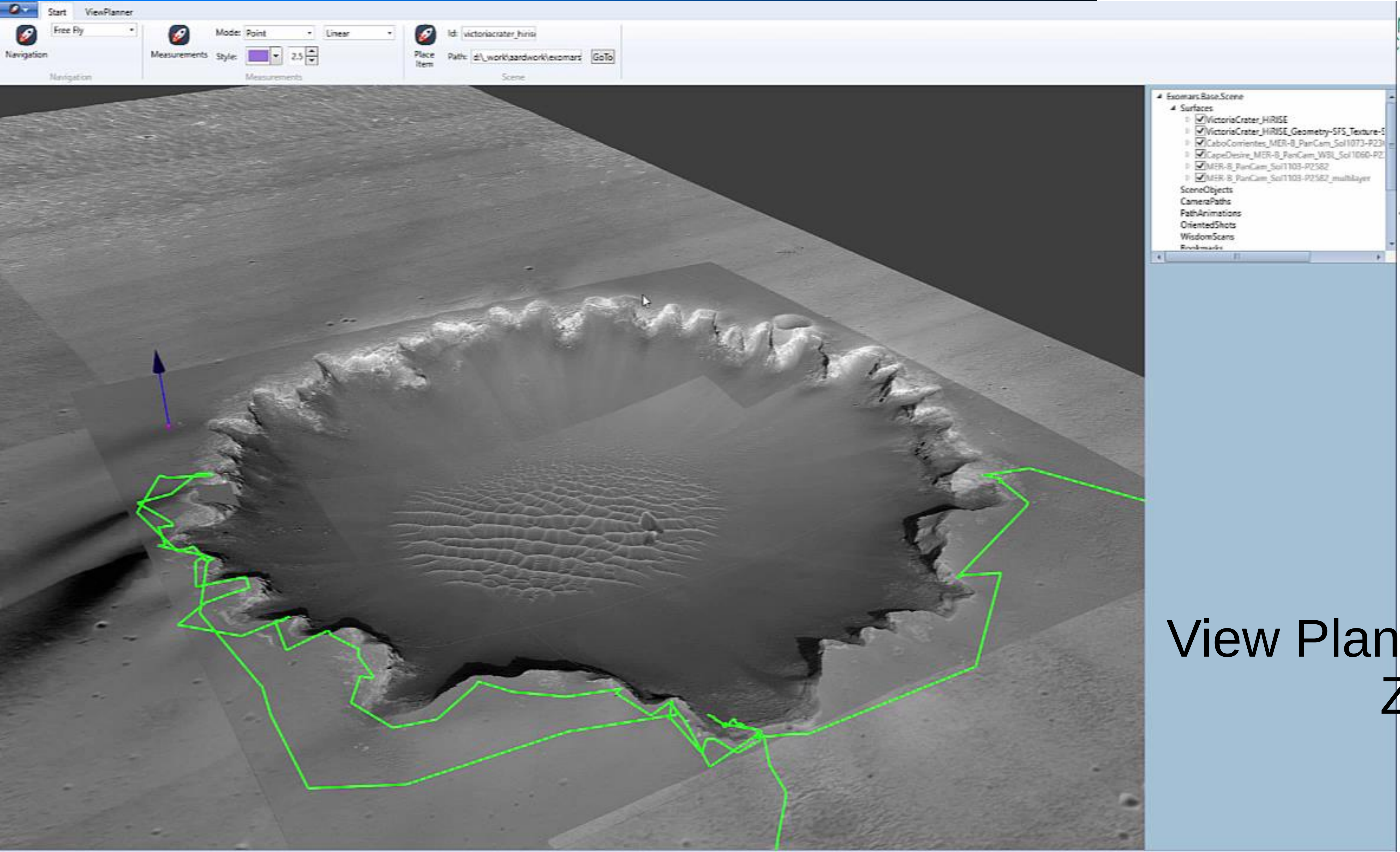
View Planner

- Simulate views
  - Cameras
  - Footprints of Instruments
- Bounding box projected onto Planet DTM / Ortho
- Dynamic / interactive display for planning
  - I/O of pointing angles



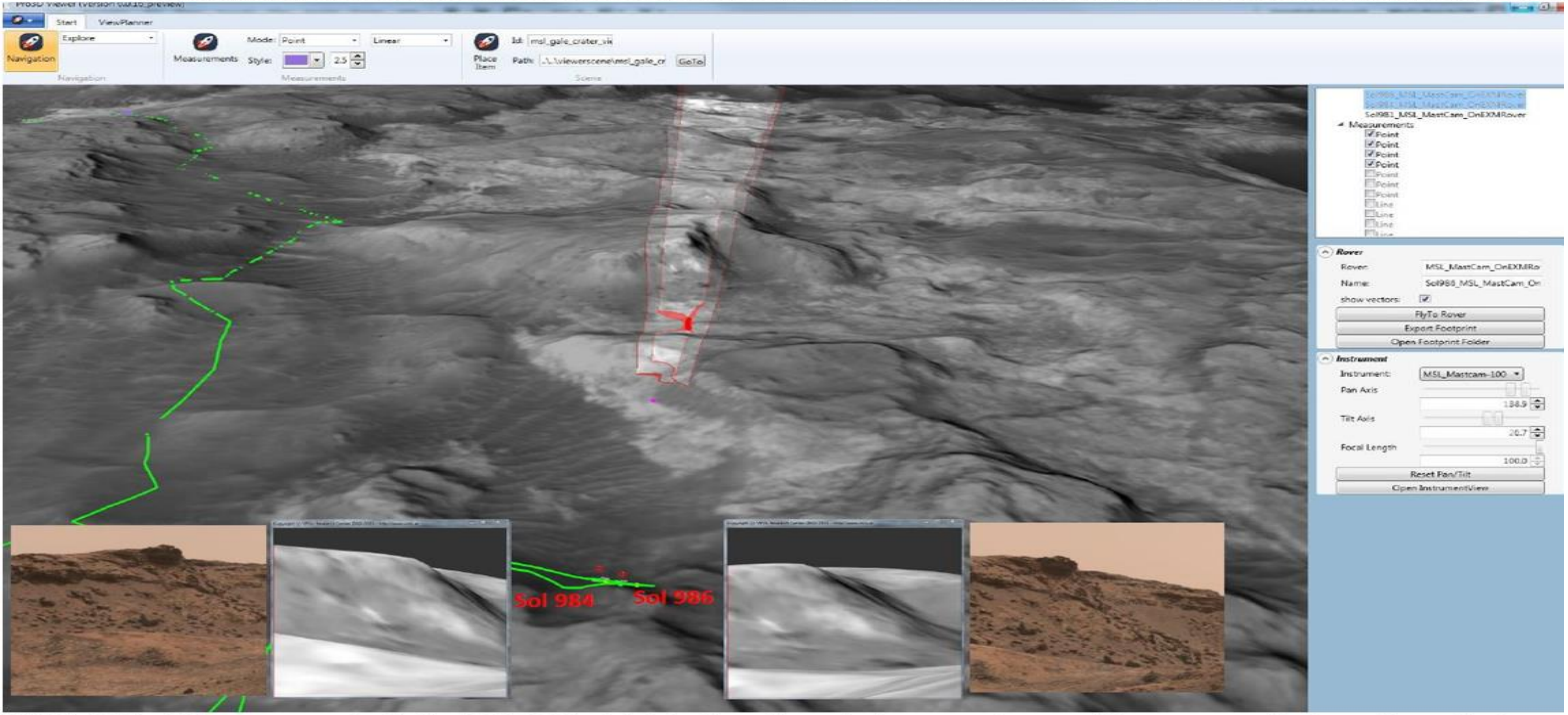
HiRISE super resolution texture:
Credits Tao & Muller, 2016


Can include
CLUPI, ISEM, TSPP, …



View Planning: Zoom

Global Wide Baseline View Planning & Verification on HiRISE DTM & ORI → Long Range Navigation DTM



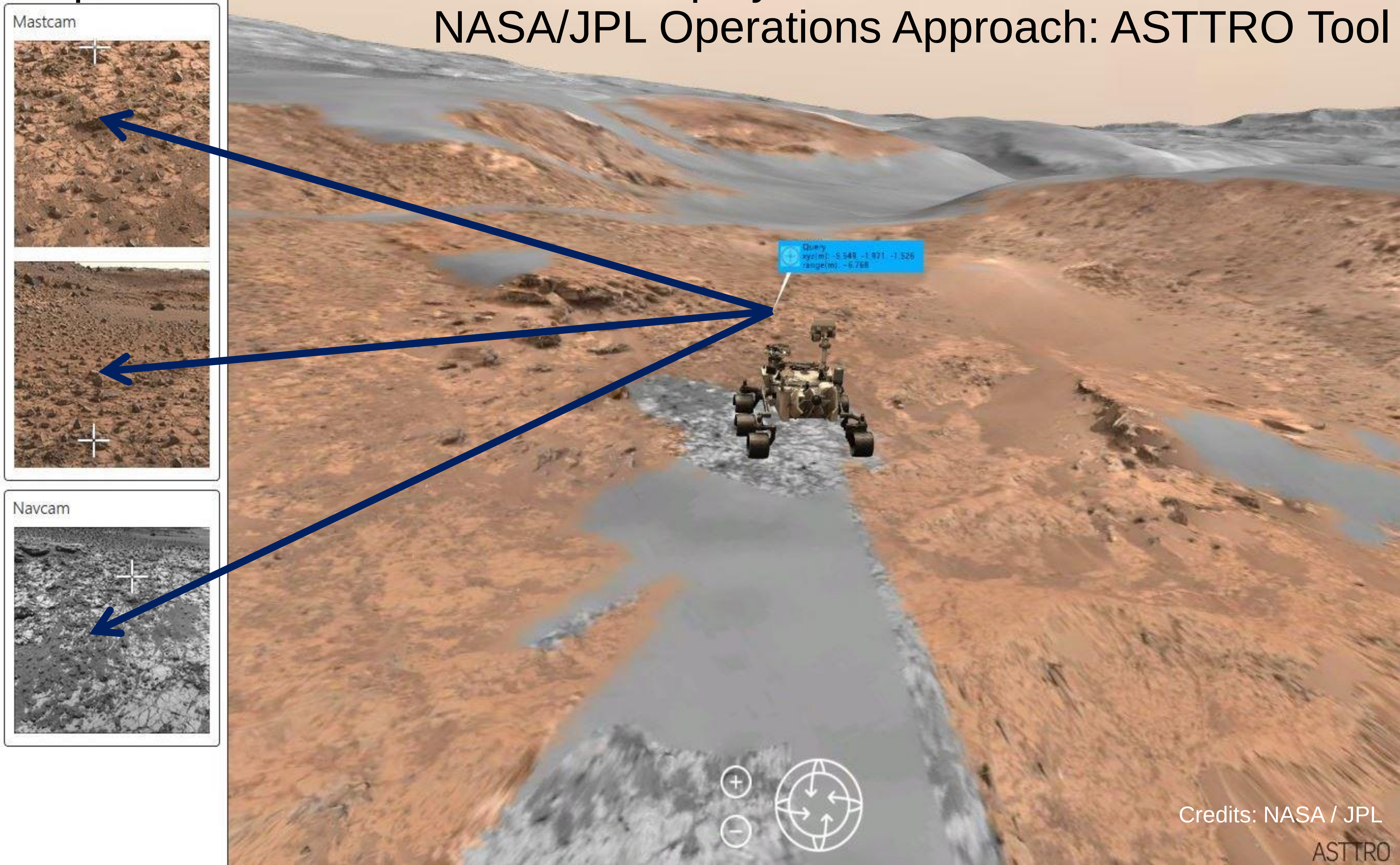
WBS MSL Mastcam pair Sols 984-986 with 7m baselength (comparing real images and virtual renderings of HiRISE base map from the same position); distance to main portions of the scene about 170m

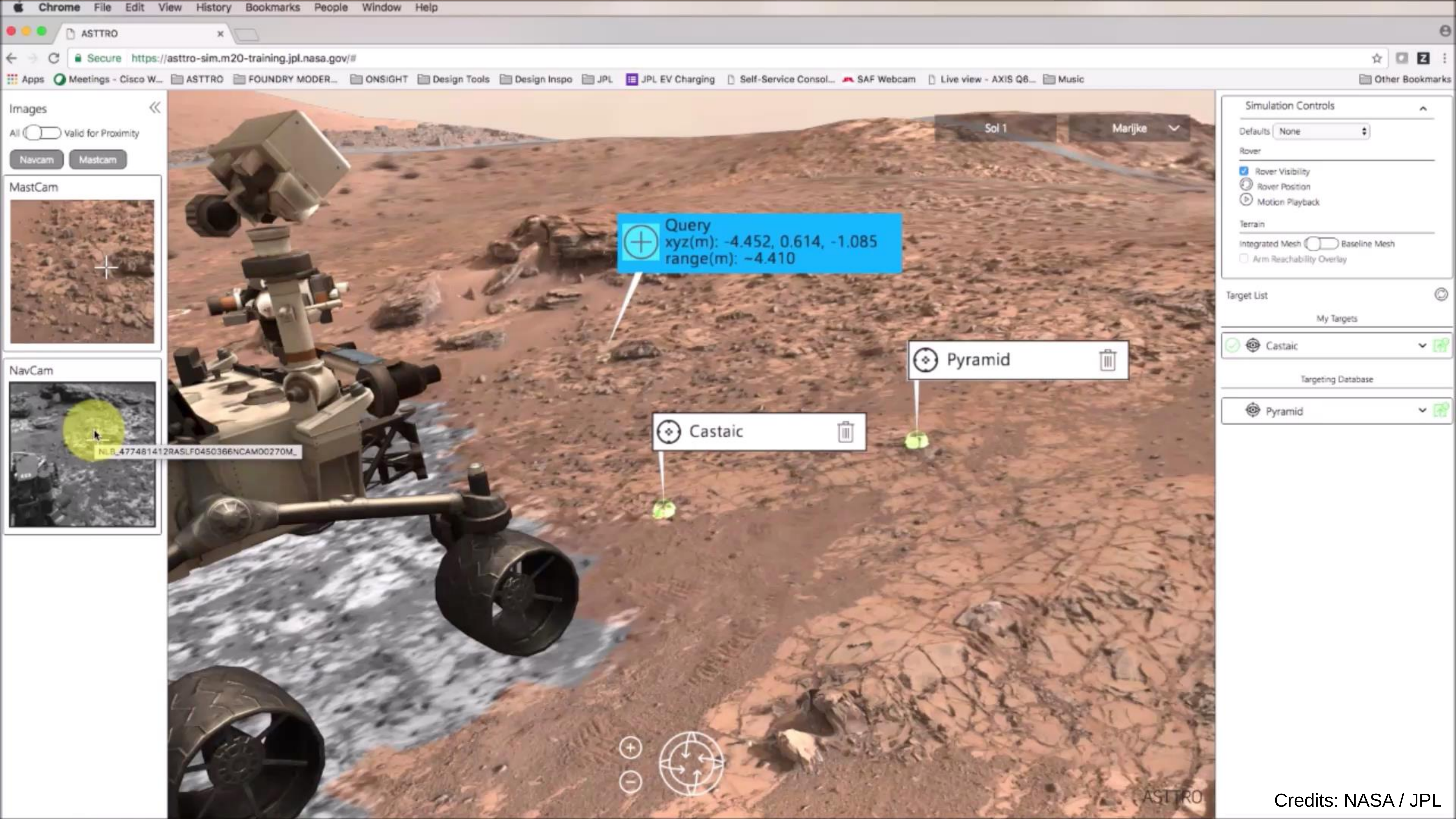
+Plan Stereo of CLUPI & PanCam & TSPP

Inspiration / Complement for maintenance & display of observations & Landmarks: NASA/JPL Operations Approach: ASTTRO Tool

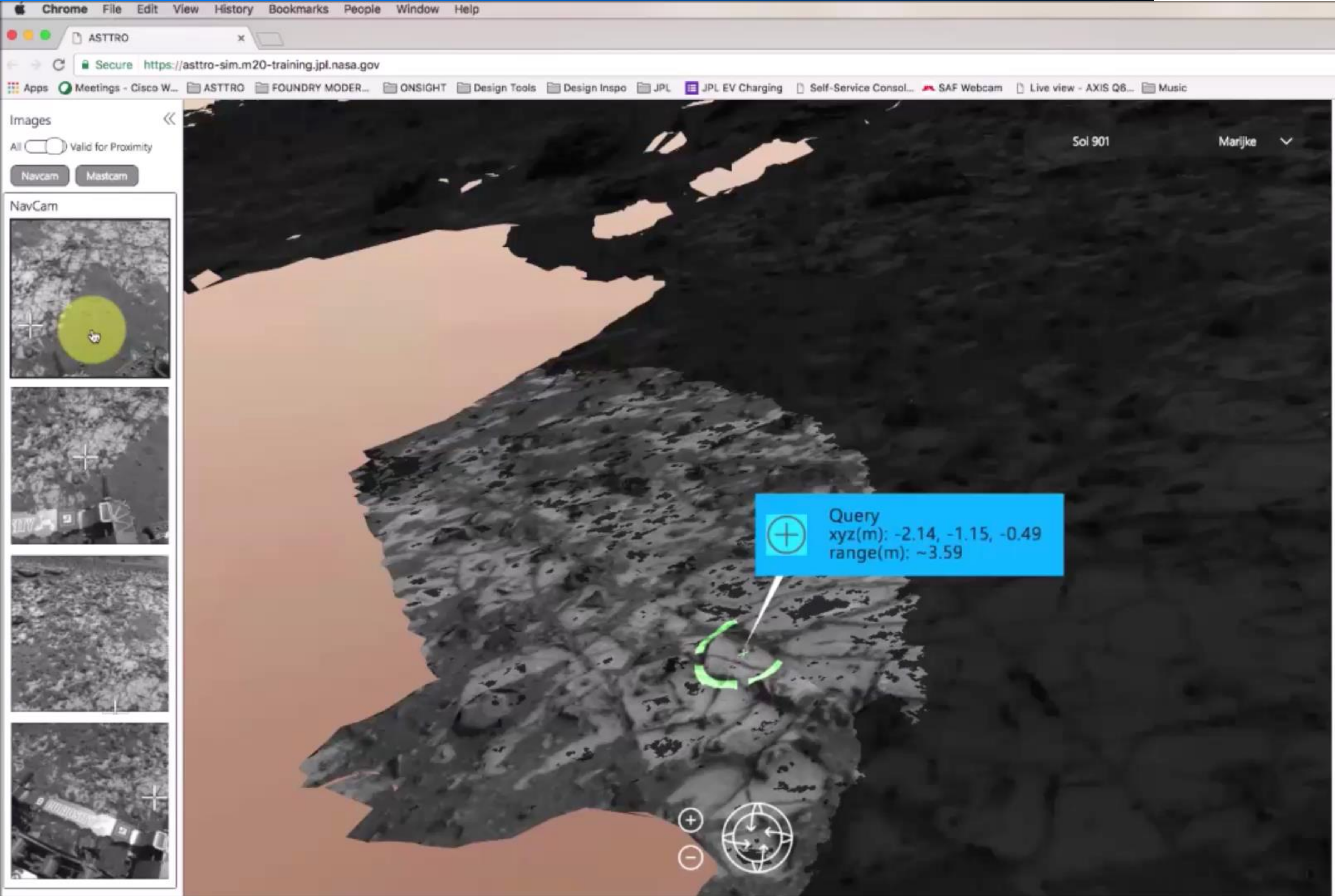
3D HiRISE & Rover 3D Augmented Database

Geo-Located Images & Target Location Displayed





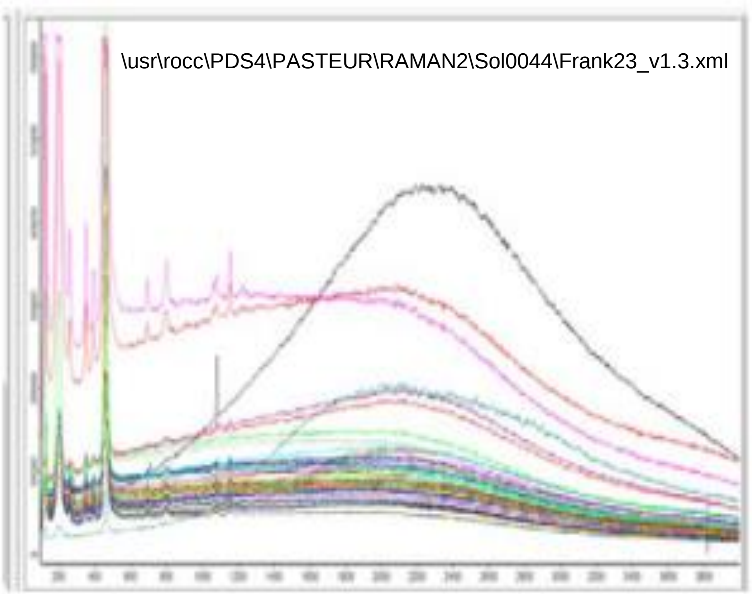
Credits: NASA / JPL



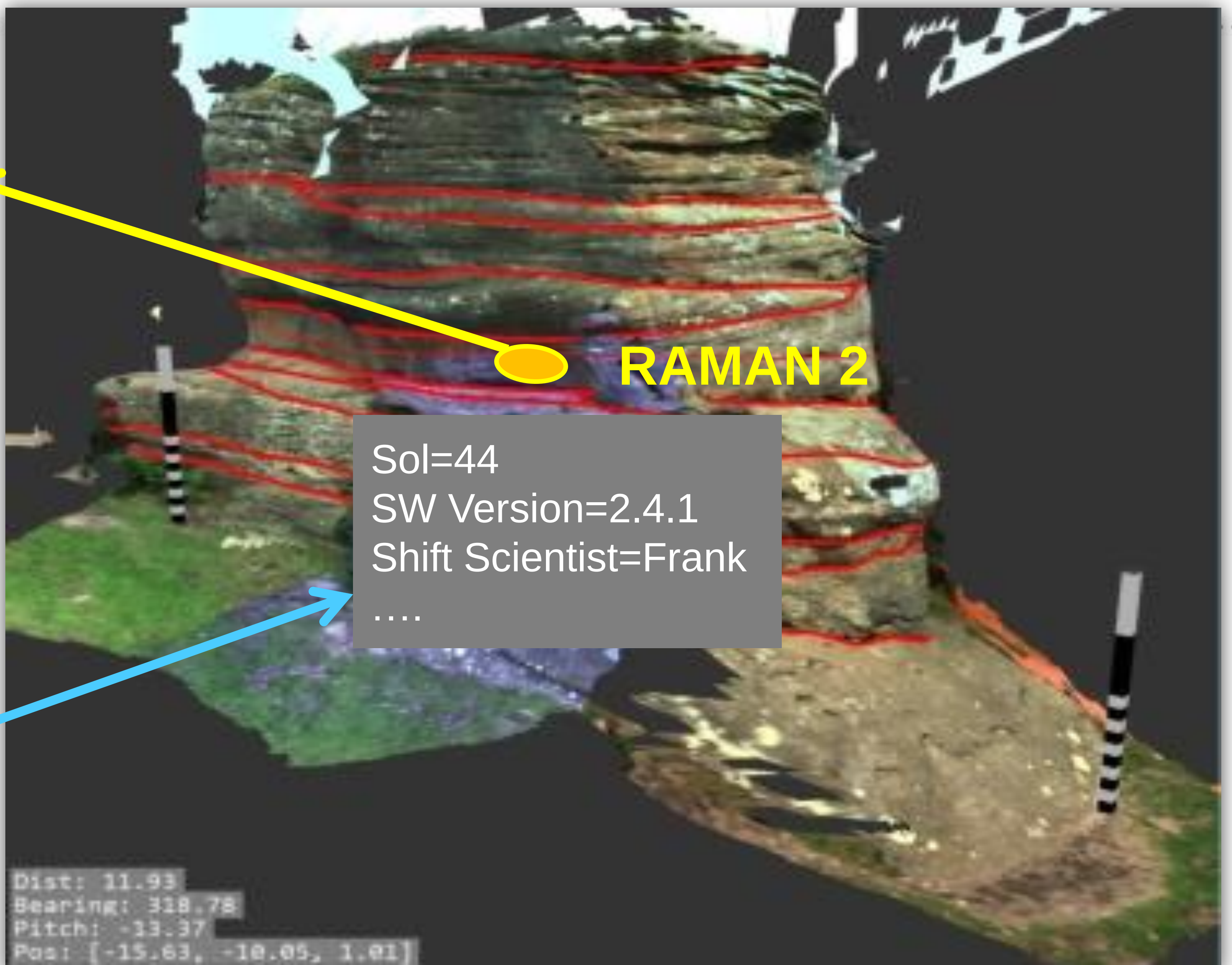
Toggle between 3D View & Geo-Registered Image

Credits: NASA / JPL

Instrument data presentation within PRo3D: Initial simplistic view



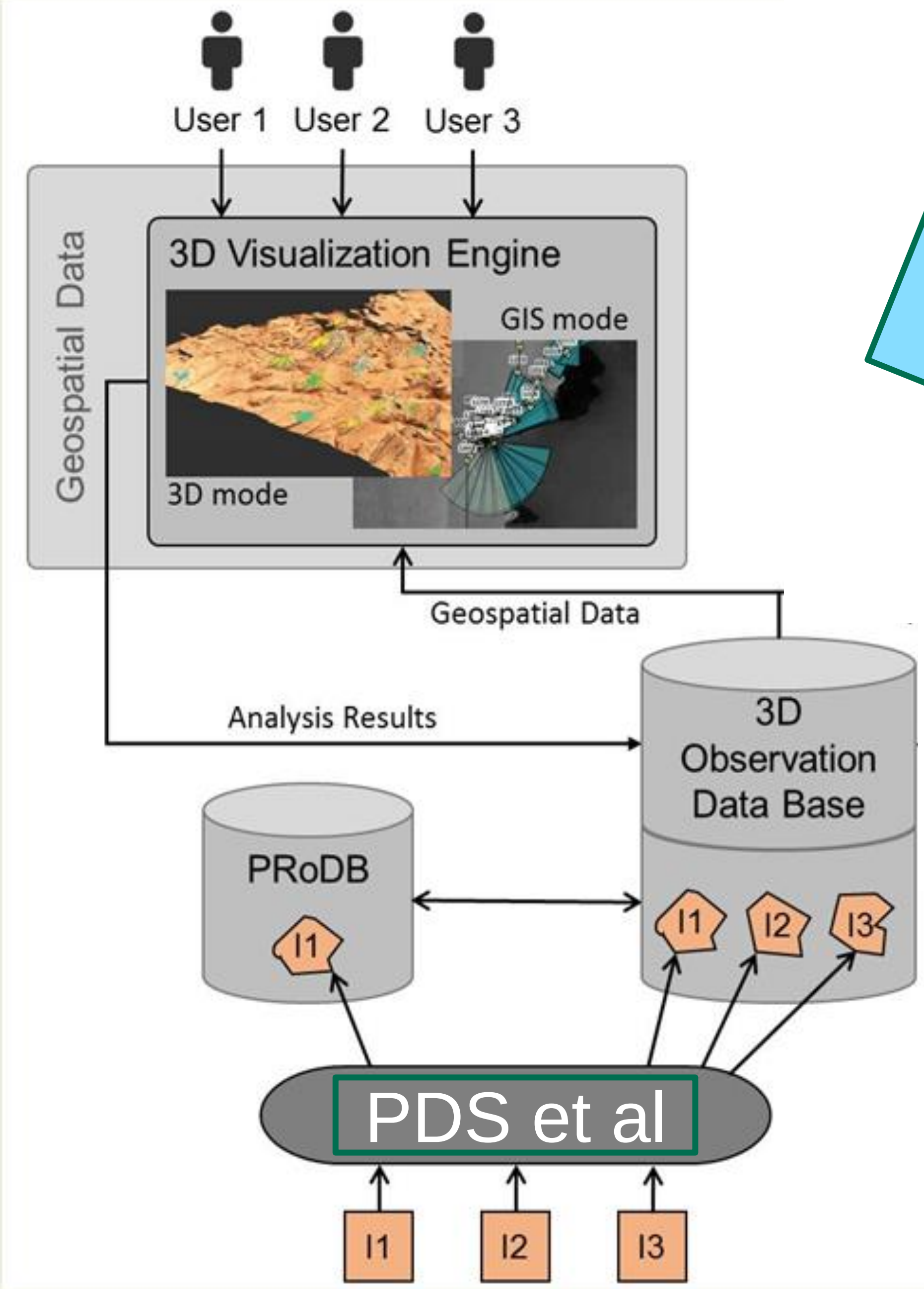
- Measurements are data blobs in 3D overview
  - Clicking therein results in
    - launch of custom presentation HMI
    - Read-out & Display of Generic Instruments Data



MINERVA Scheme

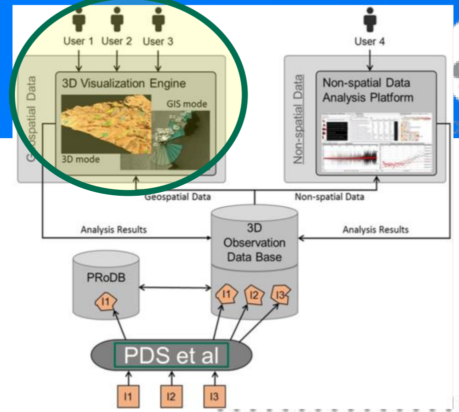
ExoMars Instruments‘ data:
- Footprints
- Frustrum
- GUID / PDS Link
- Relevant resources
  - Images
  - Spectra (ISEM, [Ma_MISS], ..)
  - H_2O% (ADRON)
  - vtk file (WISDOM)
  - Statistics
  - Specific Instruments‘ analysis

SW Launching

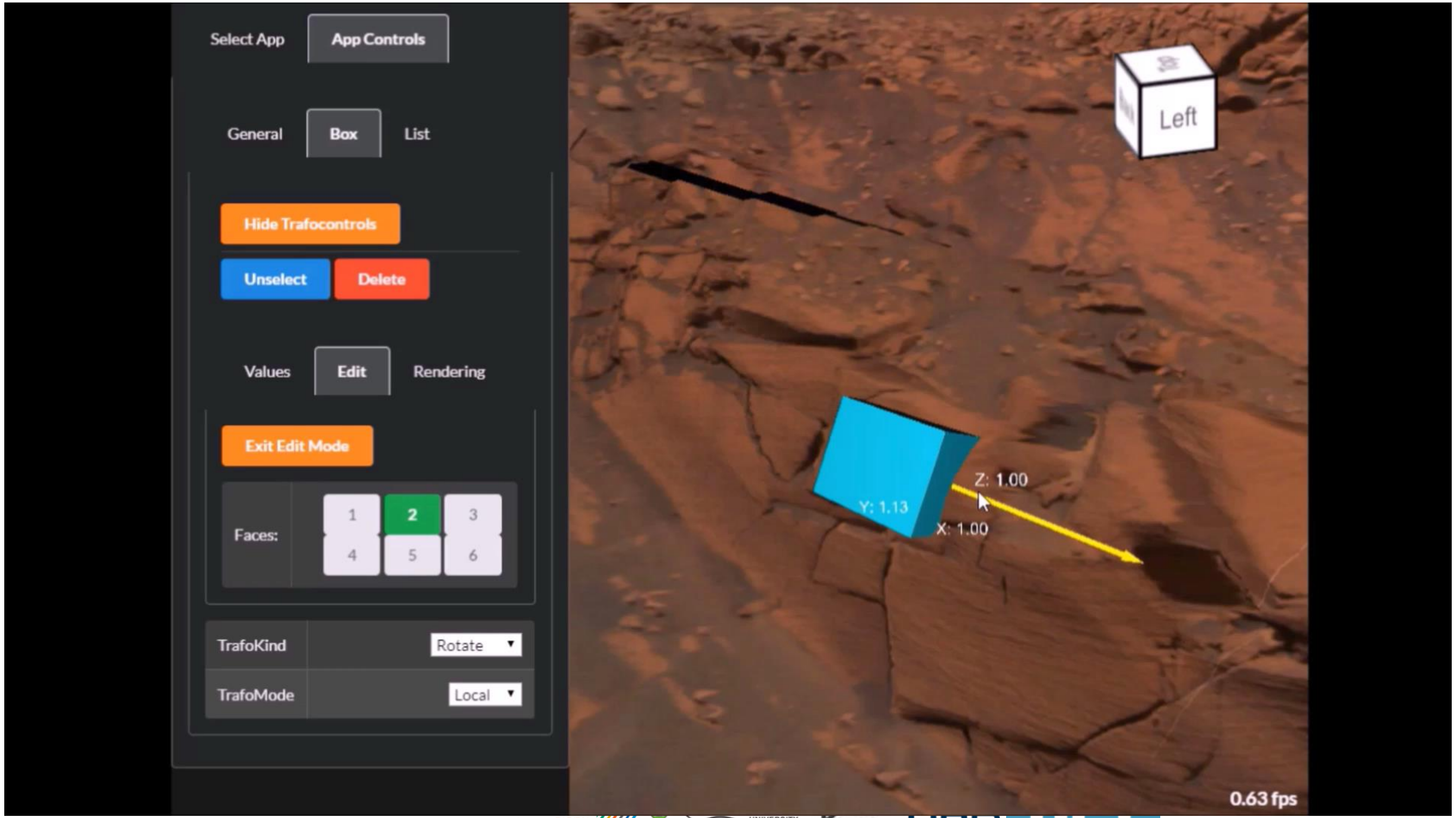


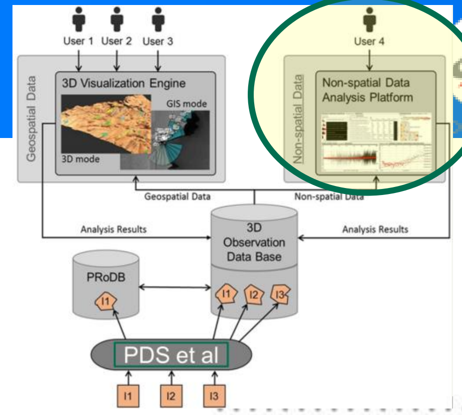
Requires PDS4 spatial cues from each Instrument!

Figure 6: MINERVA concept. The Instrument Teams (I1…I3) use the generic importer tools (or – in the case of vision – the existing vision processing results as available to JR) to ingest mission data into the 3D Observation Data Base. From there it is available to the 3D Visualization Engine with integrated GIS functionality, and the Non-spatial Data Analysis Platform. Different users can share the same locations, observations, and launch visual analysis of different instruments at a time.



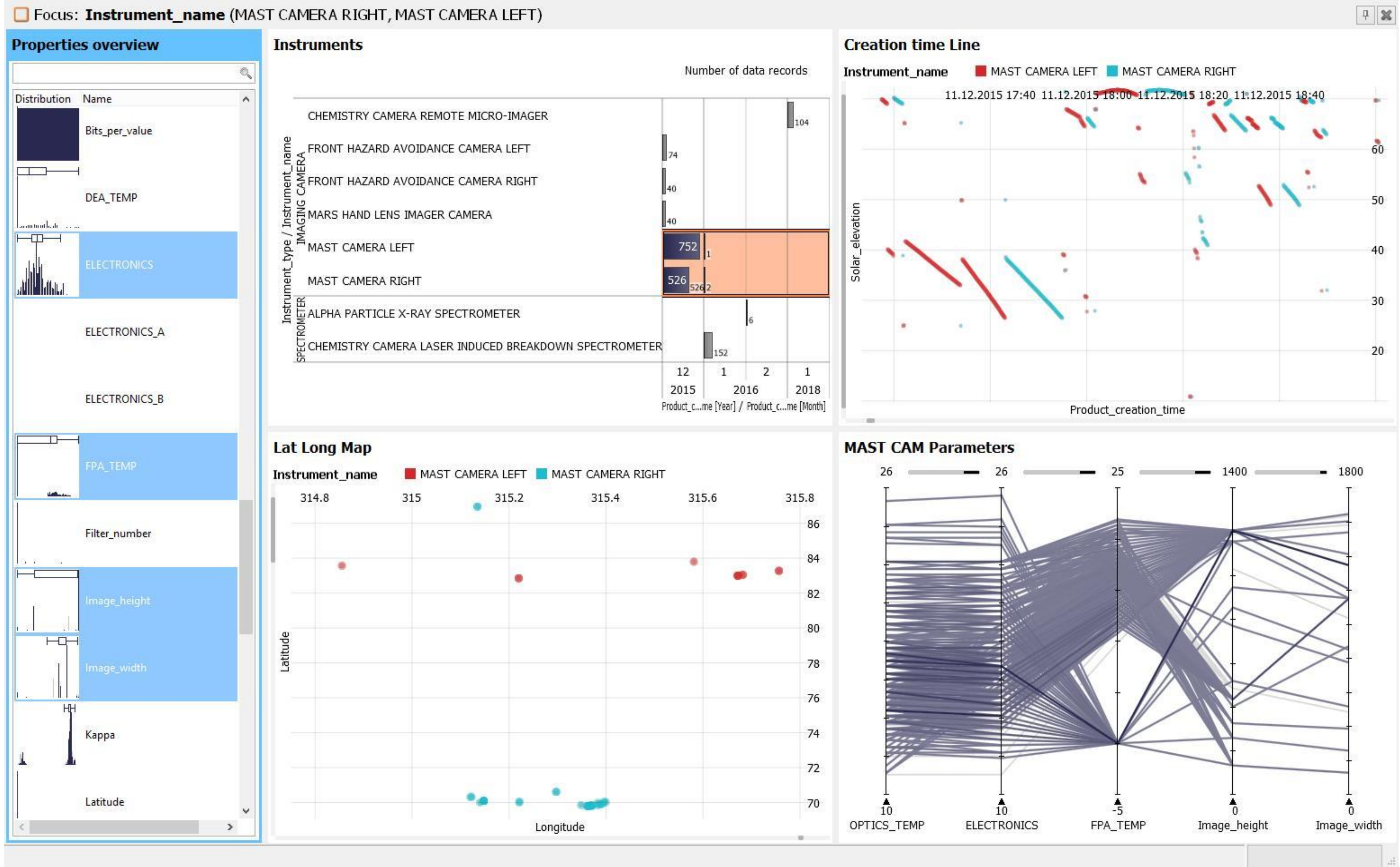
PRo3D: Exploit object representation assets to represent Instruments‘ Observations‘ footprints

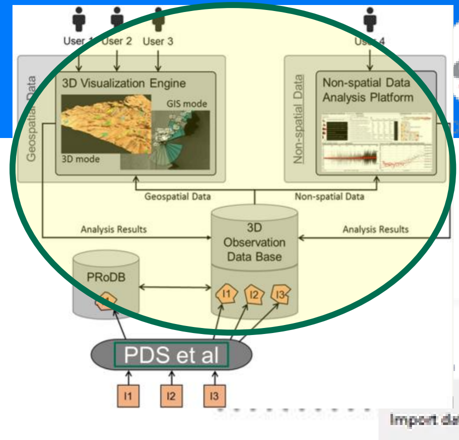




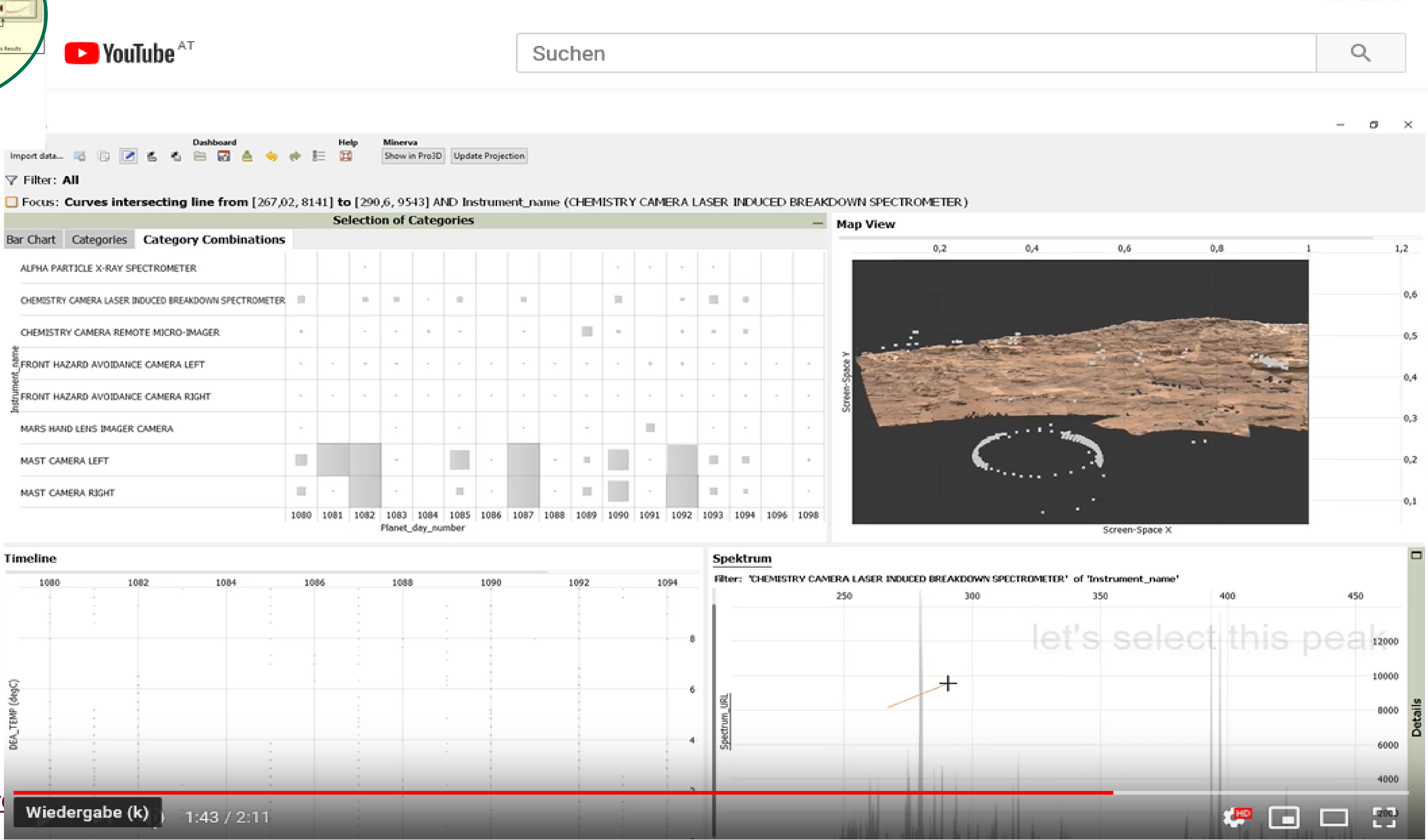
Visual Analytics: The Visplore Component

- Translating search patterns into DBMS I/F
- Direct use of meta & instrument data
- Cross references between data, meta data of different instruments
- Spatial & temporal relationship
- Finding new patterns in data
- ….Users will find out



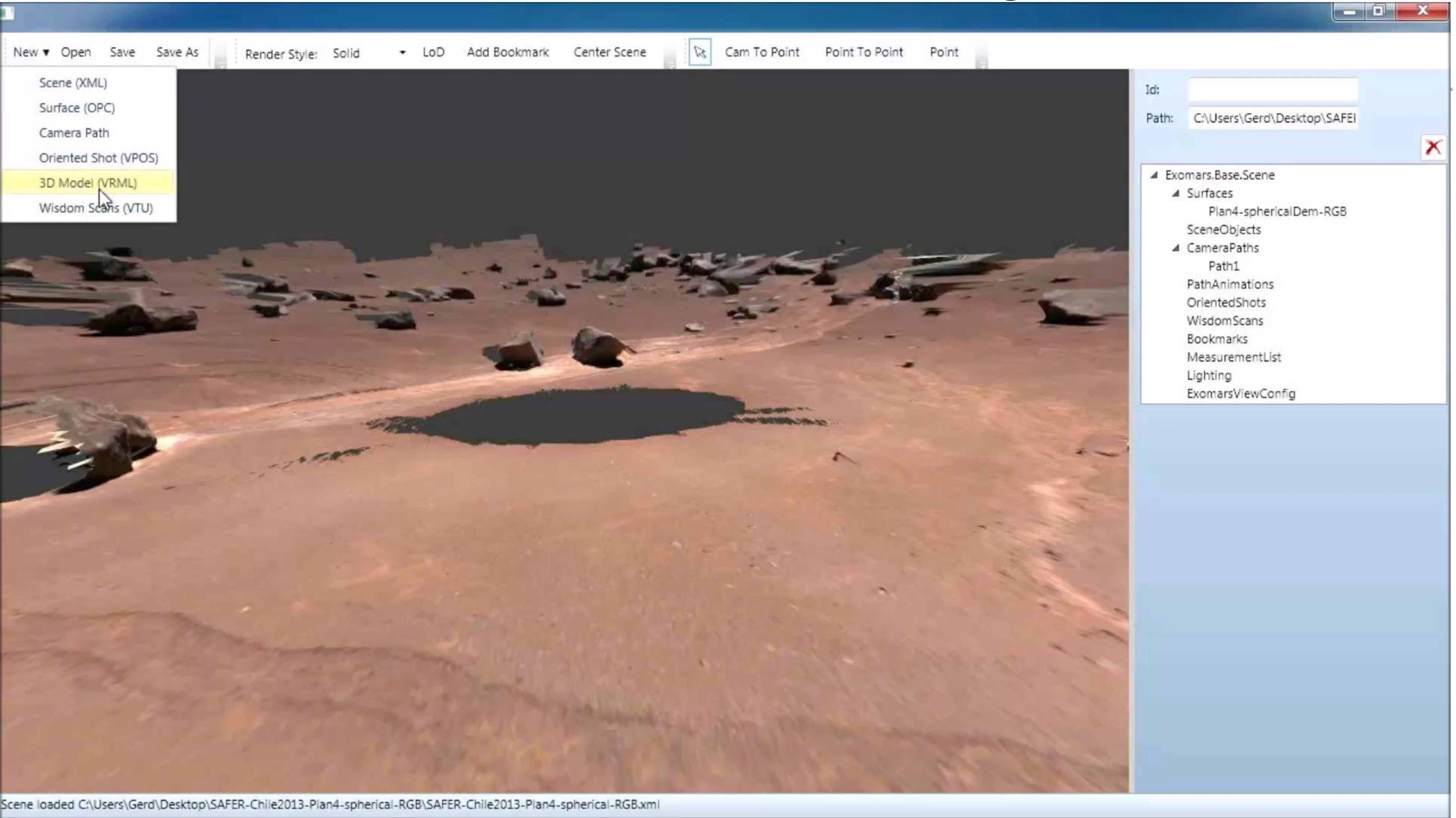


MINERVA in Operation



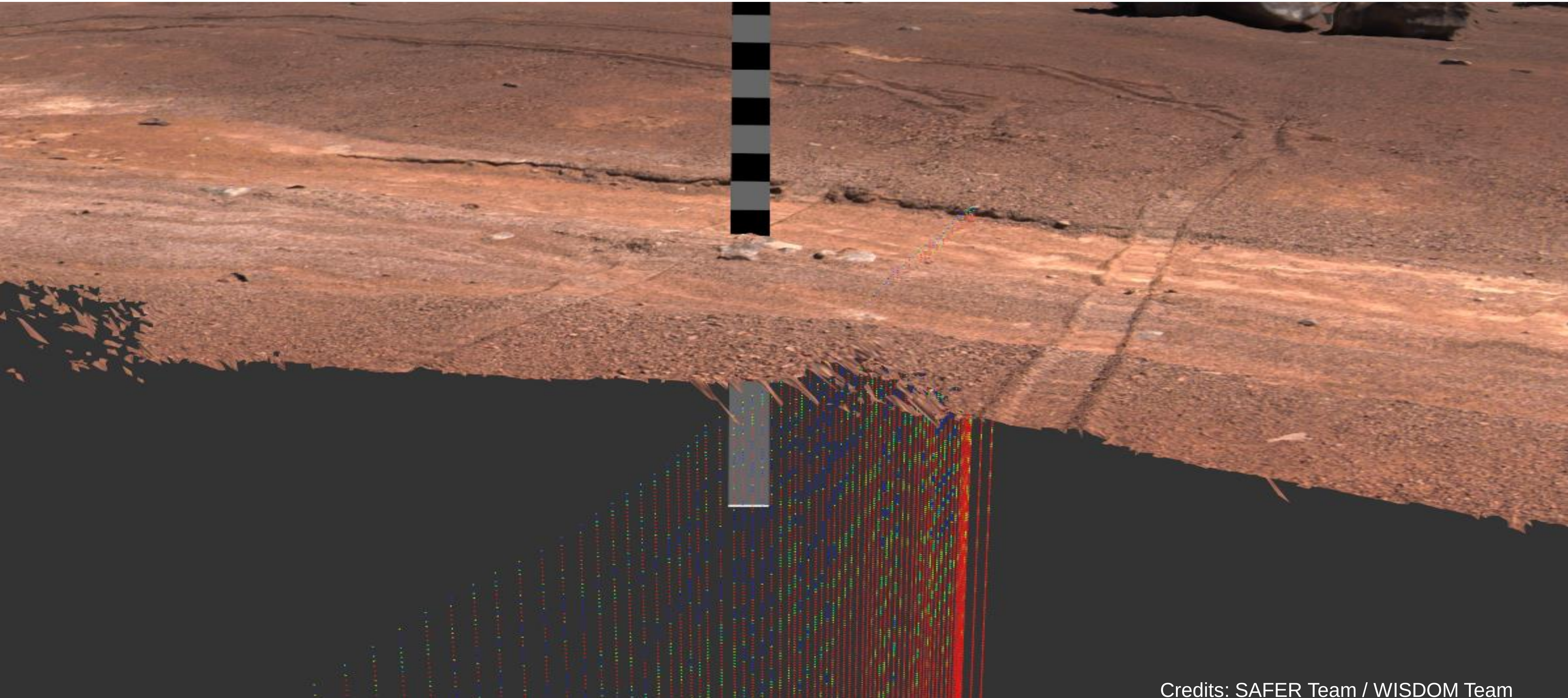
See https://www.y

WISDOM Ground Penetrating Radar Fusion



Credits:
SAFER Team /
WISDOM Team

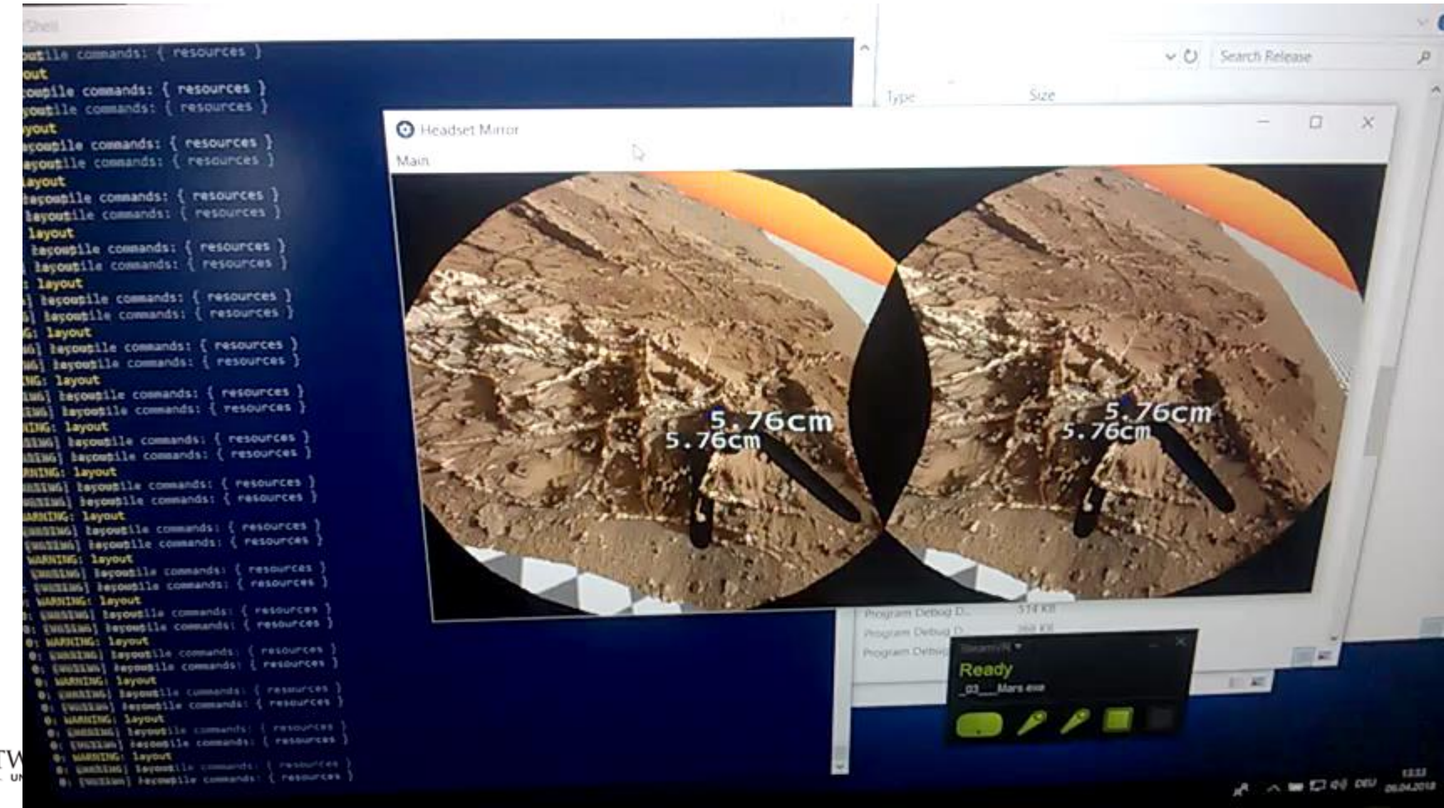
WISDOM after correct alignment



Credits: SAFER Team / WISDOM Team

Science Collaboration Aspect:Virtual Reality

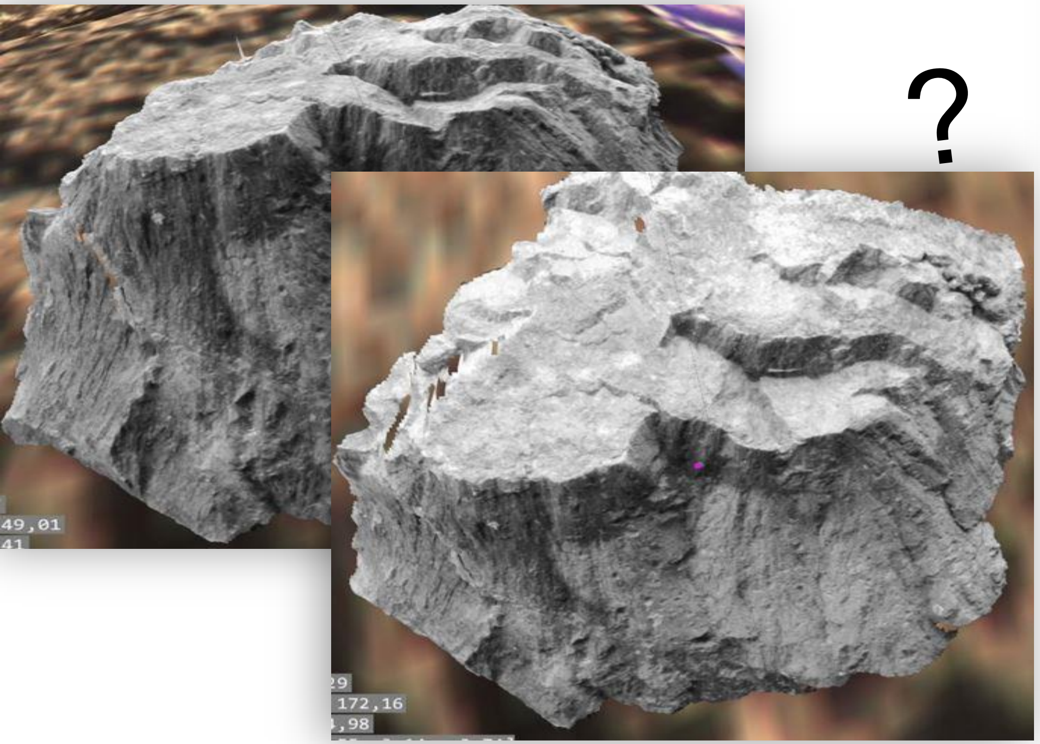
- E.g. *RAVEN* Idea by Aberystwyth University
- Interactions on 3D Context & Instruments‘ data
  - Joint annotations
  - Joint Measurements
- Multiple PRo3D instances running in parallel

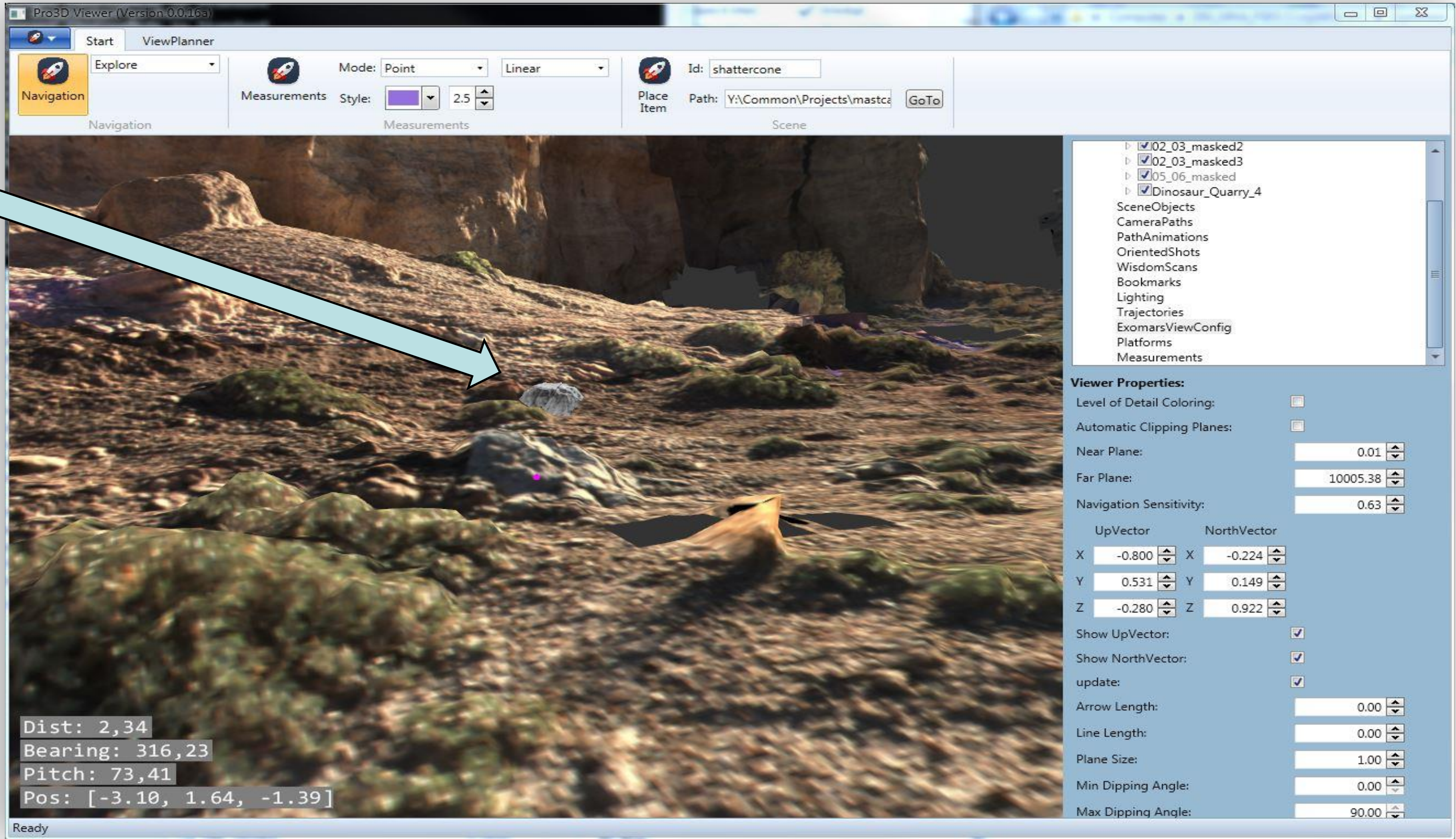


Simulation by PRo3D (e.g. for training): Place Shatter Cones within „natural“ environment

- 3D Reconstruction of real (terrestrial) shatter cones
- Place them in real scene
- Check ability to find them at certain distance

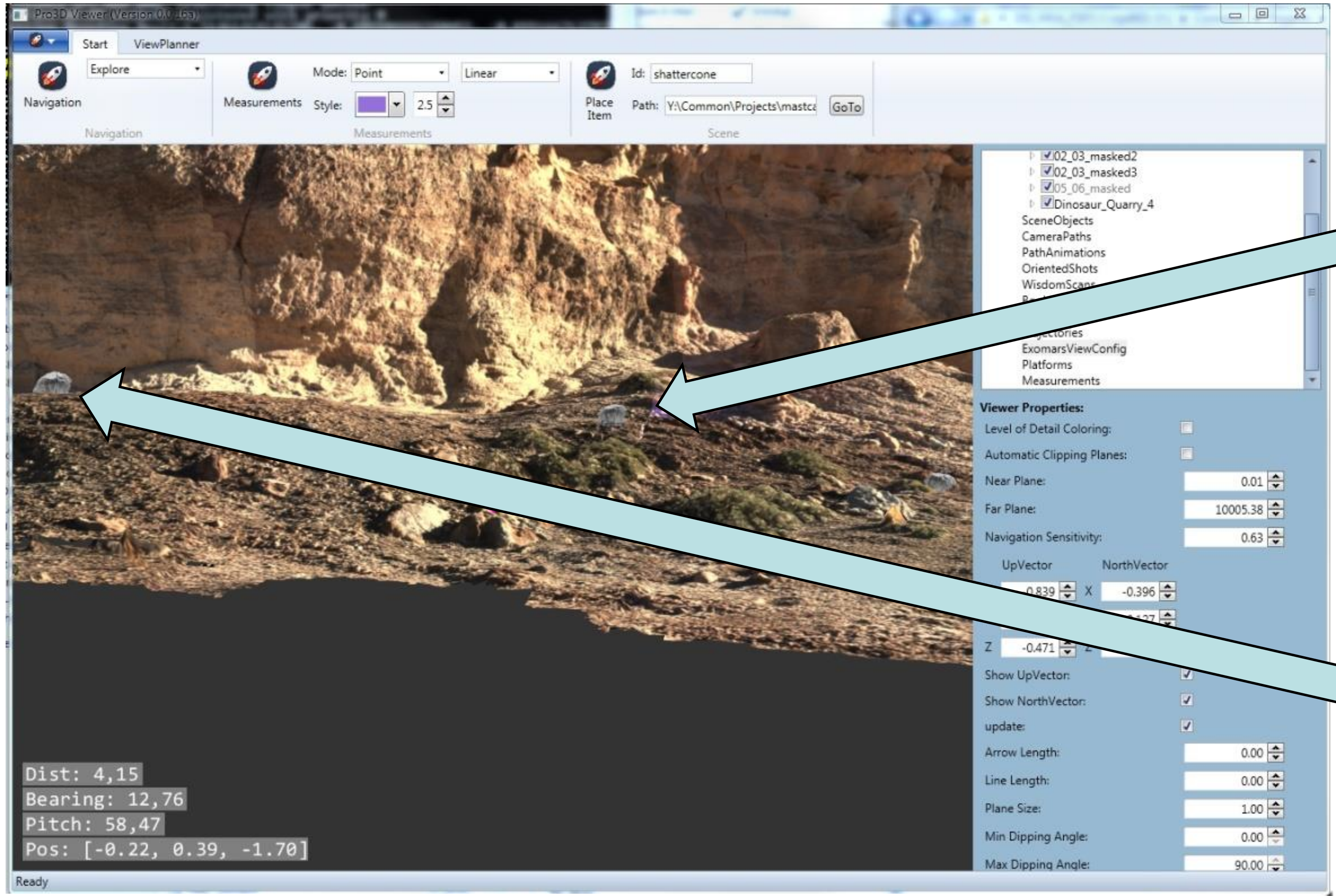
?

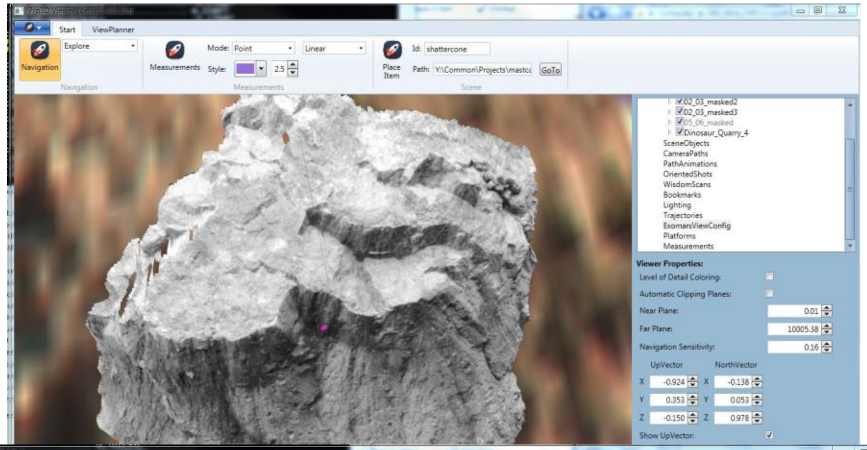


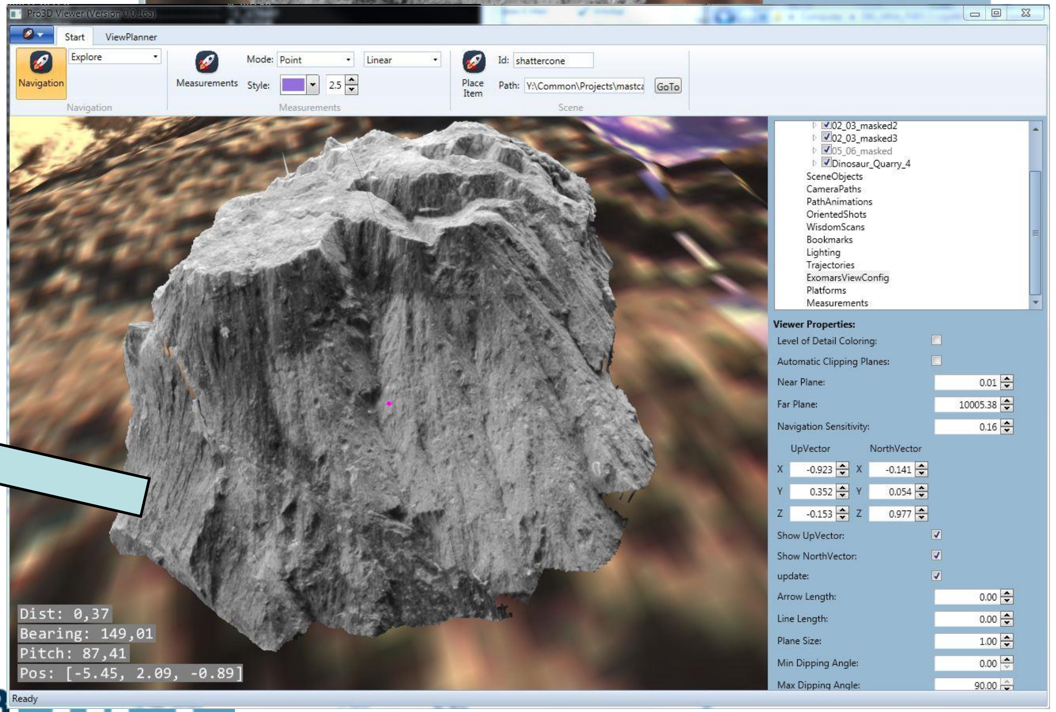


Further Examples

- Positive identification challenging, but feasible.



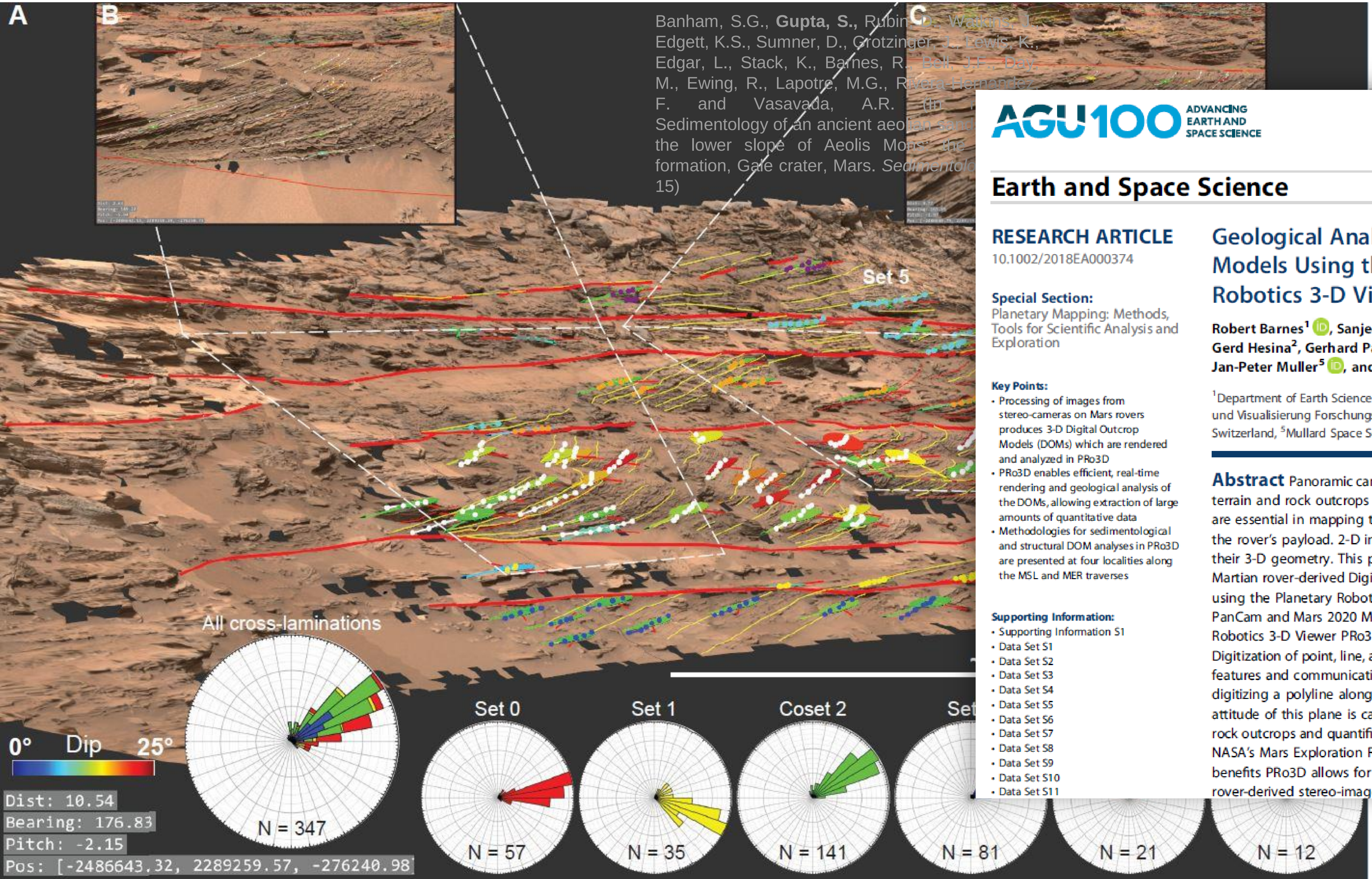




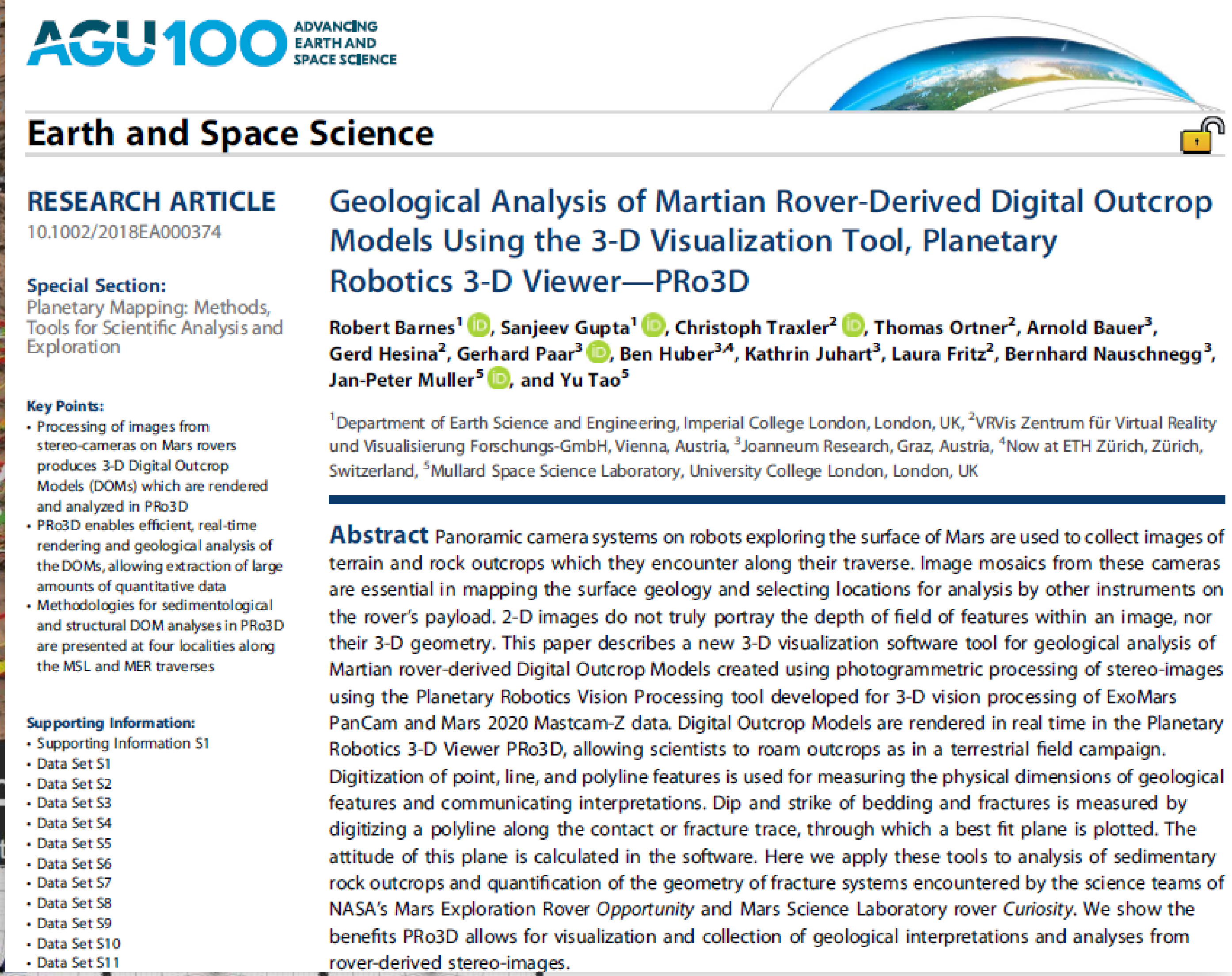
Relevant Aspects not to forget…

- Updating SPICE Kernels & Instruments‘ calibration conditions
  - Versioning in 3D products / localization of instrument data
- Archiving OPCs
  - Not PDS4 – compatible
- Maintaining a unique 3D data base (cf JPL/ASTTRO)
  - Fusion of HiRISE DTM & Rover imagery
  - Mixture between engineering & science-driven products
  - Versioning, related to source data coming in, SPICE & calibration updates,….
- Access rights to data between international teams
  - Adding credentials to each data element?
- Tools‘ et al originators to be mentioned in publications (Digital watermarks…?)
- PSA Synergies? → 3D GIS Functionality / close-range & multi-scale capabilities / ….
- …. Many more aspects, requires workshop/s & training on their own

Validation started: MSL Data Processing Results & Visualization in Use by Scientists



Barnes et al, 2018



AGU100 ADVANCING EARTH AND SPACE SCIENCE

Earth and Space Science

RESEARCH ARTICLE

10.1002/2018EA000374

Special Section:
Planetary Mapping: Methods, Tools for Scientific Analysis and Exploration

Key Points:

- Processing of images from stereo-cameras on Mars rovers produces 3-D Digital Outcrop Models (DOMs) which are rendered and analyzed in PRo3D
- PRo3D enables efficient, real-time rendering and geological analysis of the DOMs, allowing extraction of large amounts of quantitative data
- Methodologies for sedimentological and structural DOM analyses in PRo3D are presented at four localities along the MSL and MER traverses

Supporting Information:

- Supporting Information S1
- Data Set S1
- Data Set S2
- Data Set S3
- Data Set S4
- Data Set S5
- Data Set S6
- Data Set S7
- Data Set S8
- Data Set S9
- Data Set S10
- Data Set S11

Geological Analysis of Martian Rover-Derived Digital Outcrop Models Using the 3-D Visualization Tool, Planetary Robotics 3-D Viewer—PRo3D

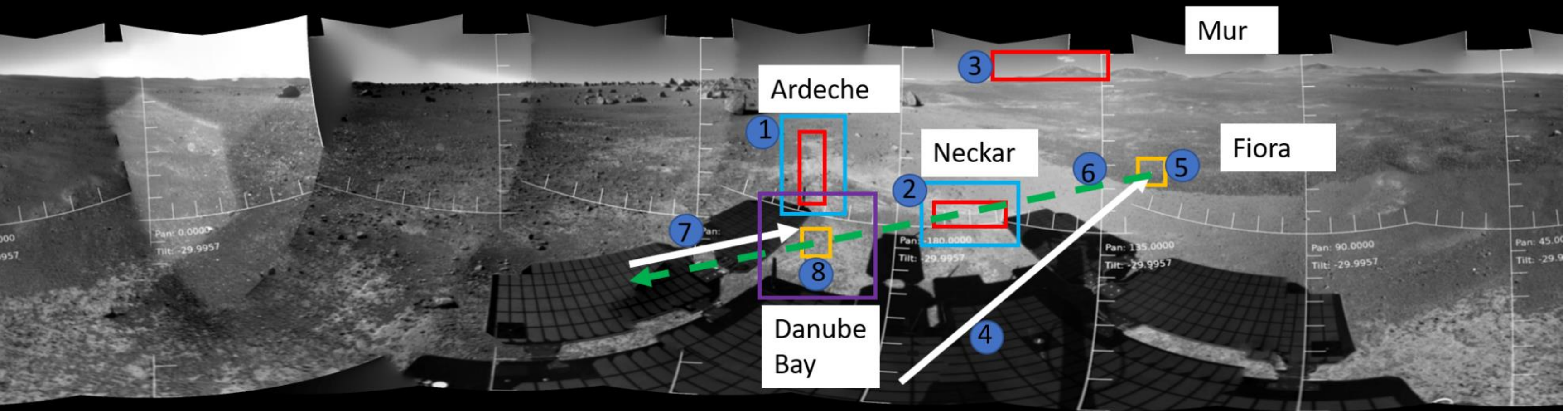
Robert Barnes[1], Sanjeev Gupta[1], Christoph Traxler[2], Thomas Ortner[2], Arnold Bauer[3], Gerd Hesina[2], Gerhard Paar[3], Ben Huber[3,4], Kathrin Juhart[3], Laura Fritz[2], Bernhard Nauschnegg[3], Jan-Peter Muller[5], and Yu Tao[5]

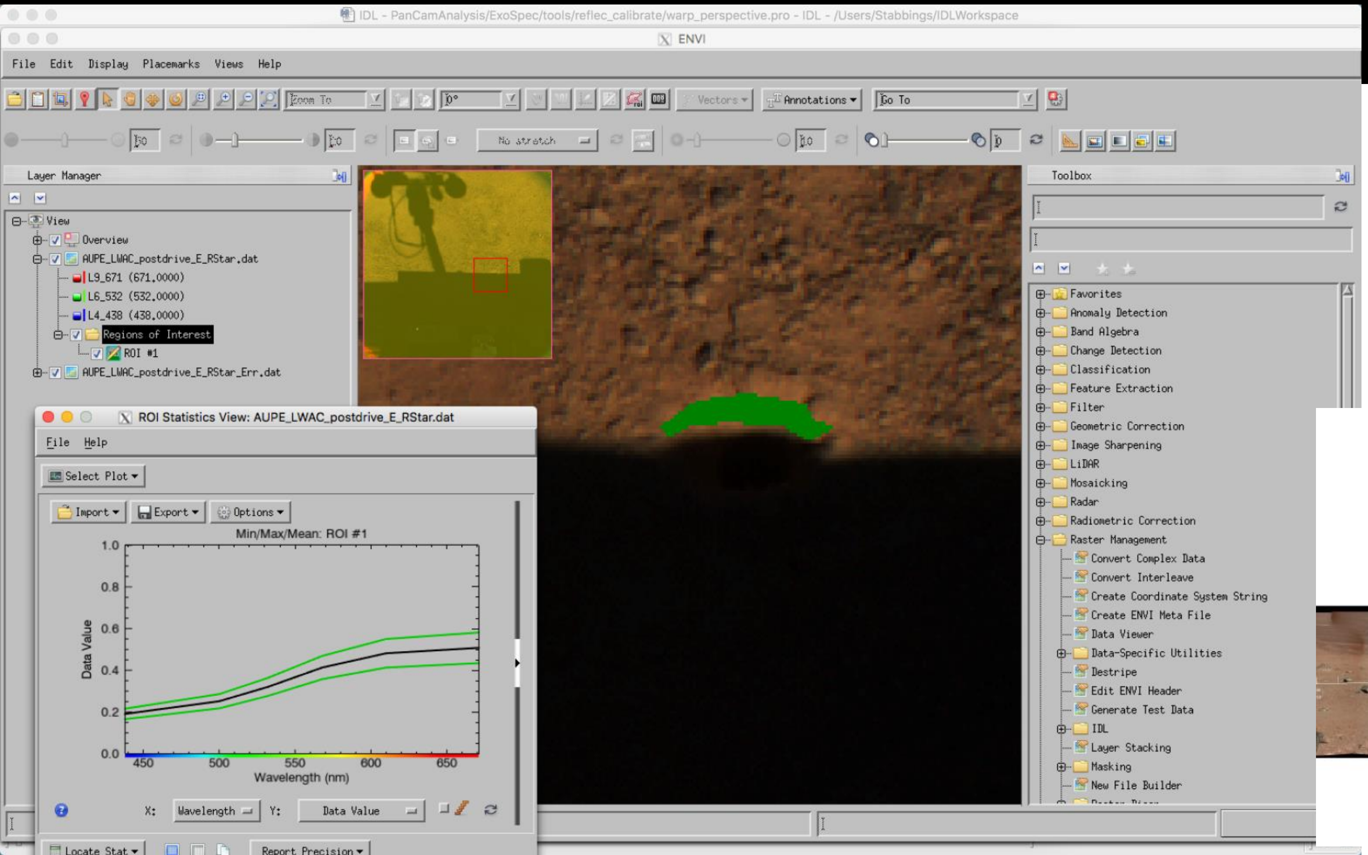
[1]Department of Earth Science and Engineering, Imperial College London, London, UK, [2]VRVis Zentrum für Virtual Reality und Visualisierung Forschungs-GmbH, Vienna, Austria, [3]Joanneum Research, Graz, Austria, [4]Now at ETH Zürich, Zürich, Switzerland, [5]Mullard Space Science Laboratory, University College London, London, UK

Abstract Panoramic camera systems on robots exploring the surface of Mars are used to collect images of terrain and rock outcrops which they encounter along their traverse. Image mosaics from these cameras are essential in mapping the surface geology and selecting locations for analysis by other instruments on the rover's payload. 2-D images do not truly portray the depth of field of features within an image, nor their 3-D geometry. This paper describes a new 3-D visualization software tool for geological analysis of Martian rover-derived Digital Outcrop Models created using photogrammetric processing of stereo-images using the Planetary Robotics Vision Processing tool developed for 3-D vision processing of ExoMars PanCam and Mars 2020 Mastcam-Z data. Digital Outcrop Models are rendered in real time in the Planetary Robotics 3-D Viewer PRo3D, allowing scientists to roam outcrops as in a terrestrial field campaign. Digitization of point, line, and polyline features is used for measuring the physical dimensions of geological features and communicating interpretations. Dip and strike of bedding and fractures is measured by digitizing a polyline along the contact or fracture trace, through which a best fit plane is plotted. The attitude of this plane is calculated in the software. Here we apply these tools to analysis of sedimentary rock outcrops and quantification of the geometry of fracture systems encountered by the science teams of NASA's Mars Exploration Rover *Opportunity* and Mars Science Laboratory rover *Curiosity*. We show the benefits PRo3D allows for visualization and collection of geological interpretations and analyses from rover-derived stereo-images.

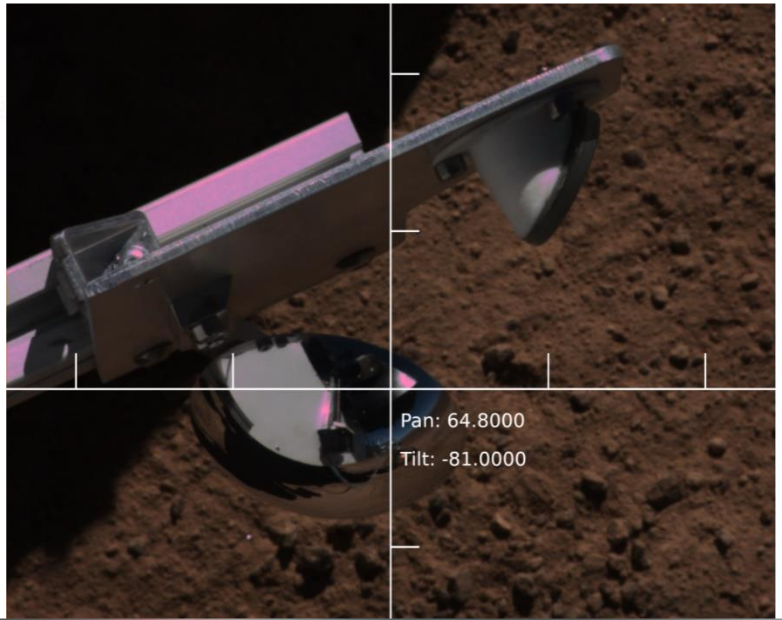
On Panorama Viewing…

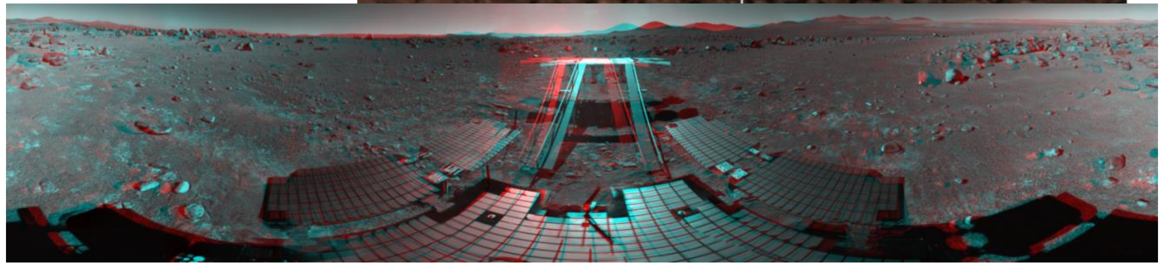
HRC CLUPI ISEM WAC WISDOM

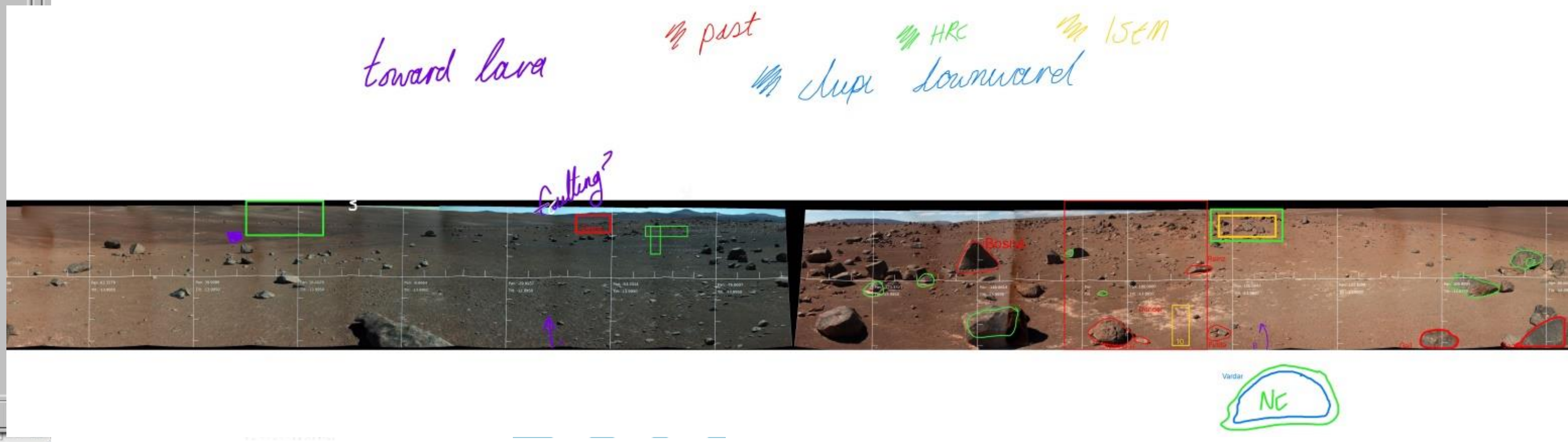




ExoFit Examples



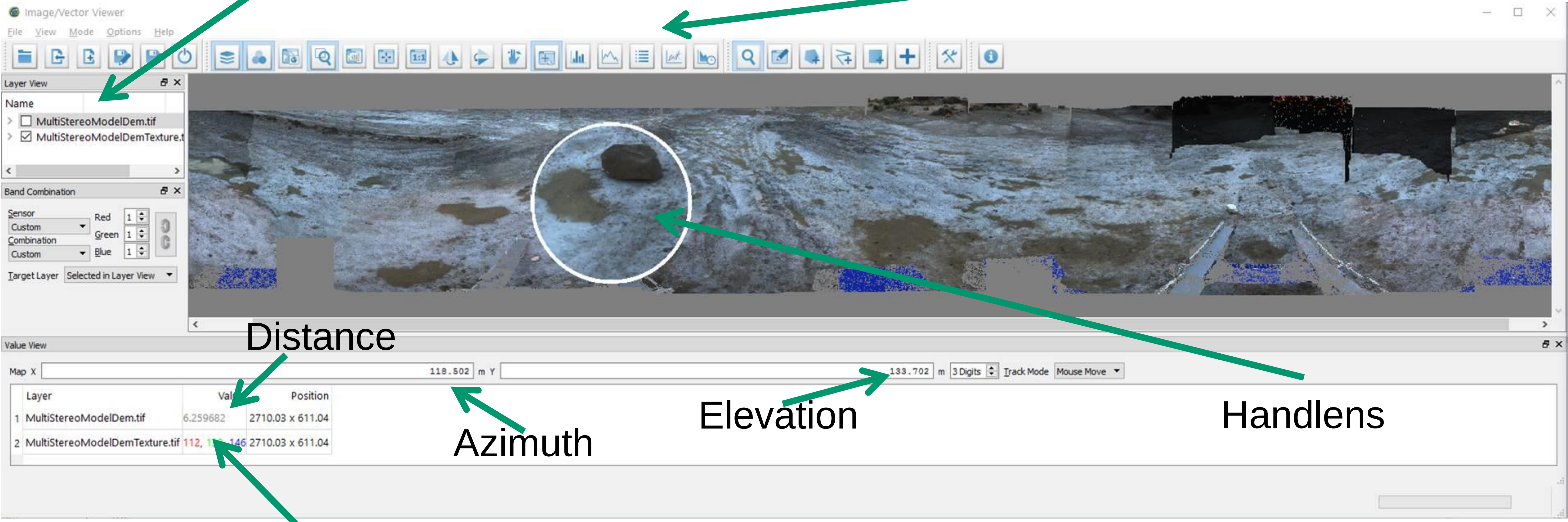




Currently discussing: JR ImageVector Viewer (ImpactViewer): Panoramas & (multispectral) Images

Arbitrary layers: Distance, filters, …

Various analysis & edit modes, configurable



Distance

Azimuth

Elevation

Handlens

Color Values