Mapping Mars Using Virtual Reality: The Pathfinder Experience

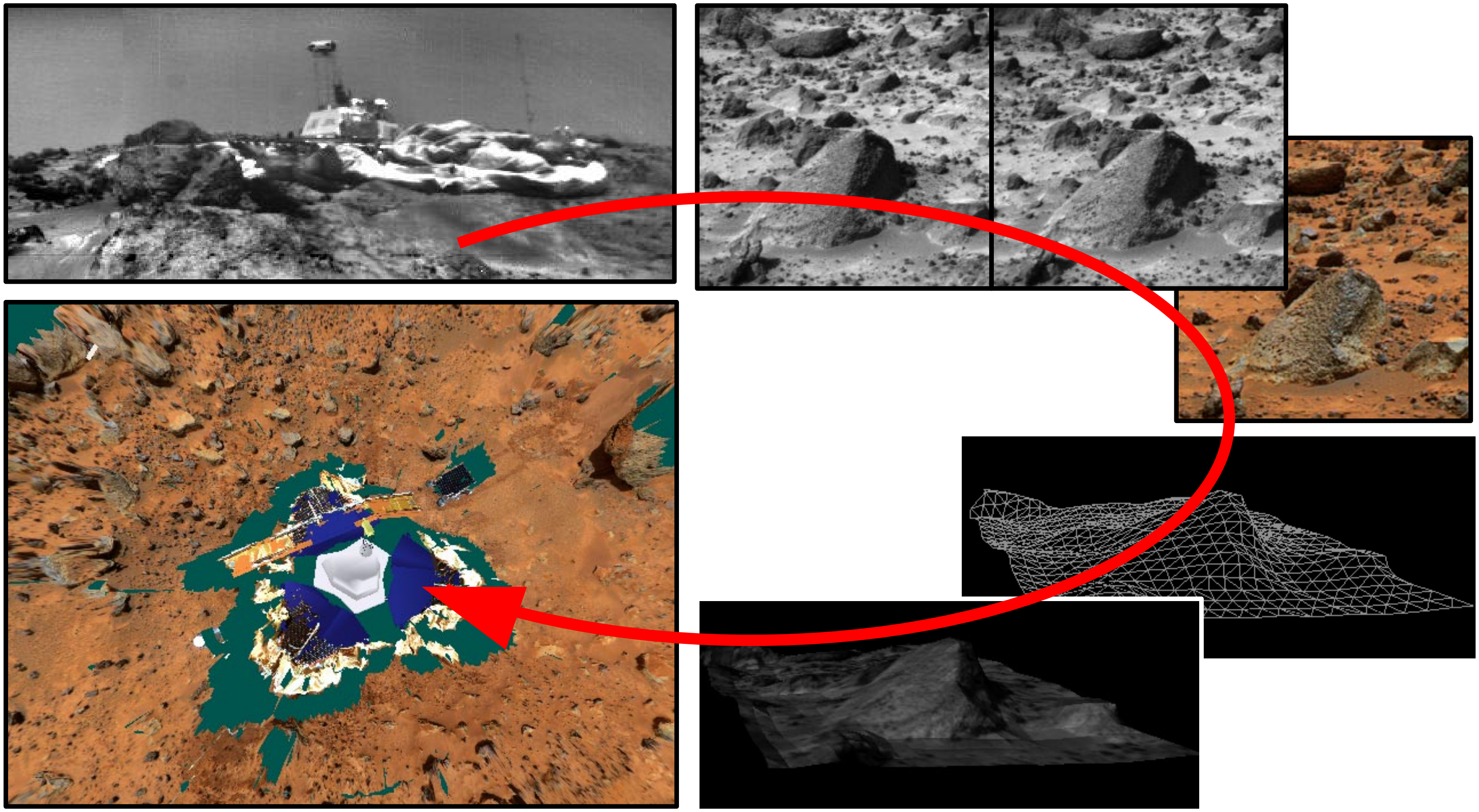
E. Zbinden,

C. Stoker, T. Blackmon, K. Schwehr,
P. Henning, C. Neveu, B. Kanefsky.

Intelligent Mechanisms Group, NASA Ames Research Center,
Moffett Field, CA, USA
CAELUM Research Corporation - Recom Technologies

zbinden@artemis.arc.nasa.gov

Photo-Realistic Terrain Modeling



Objectives

1. Automatically generate photo-realistic terrain models at downlink rate and with low latency

2. Validate the use of virtual reality interfaces for science analysis and day to day mission planning

- **Remote Processing of the Data at NASA Ames (limited space at SFOF)**
- **Turn around time under 30 minutes**
- **Render the models at frame rate allowing real time user interaction**

Clients

- **Pathfinder Scientists**
- **Mission controllers and rover operators**
- **Low Resolution VRML Models Available to the General Public via the Internet**
- **Public Outreach**

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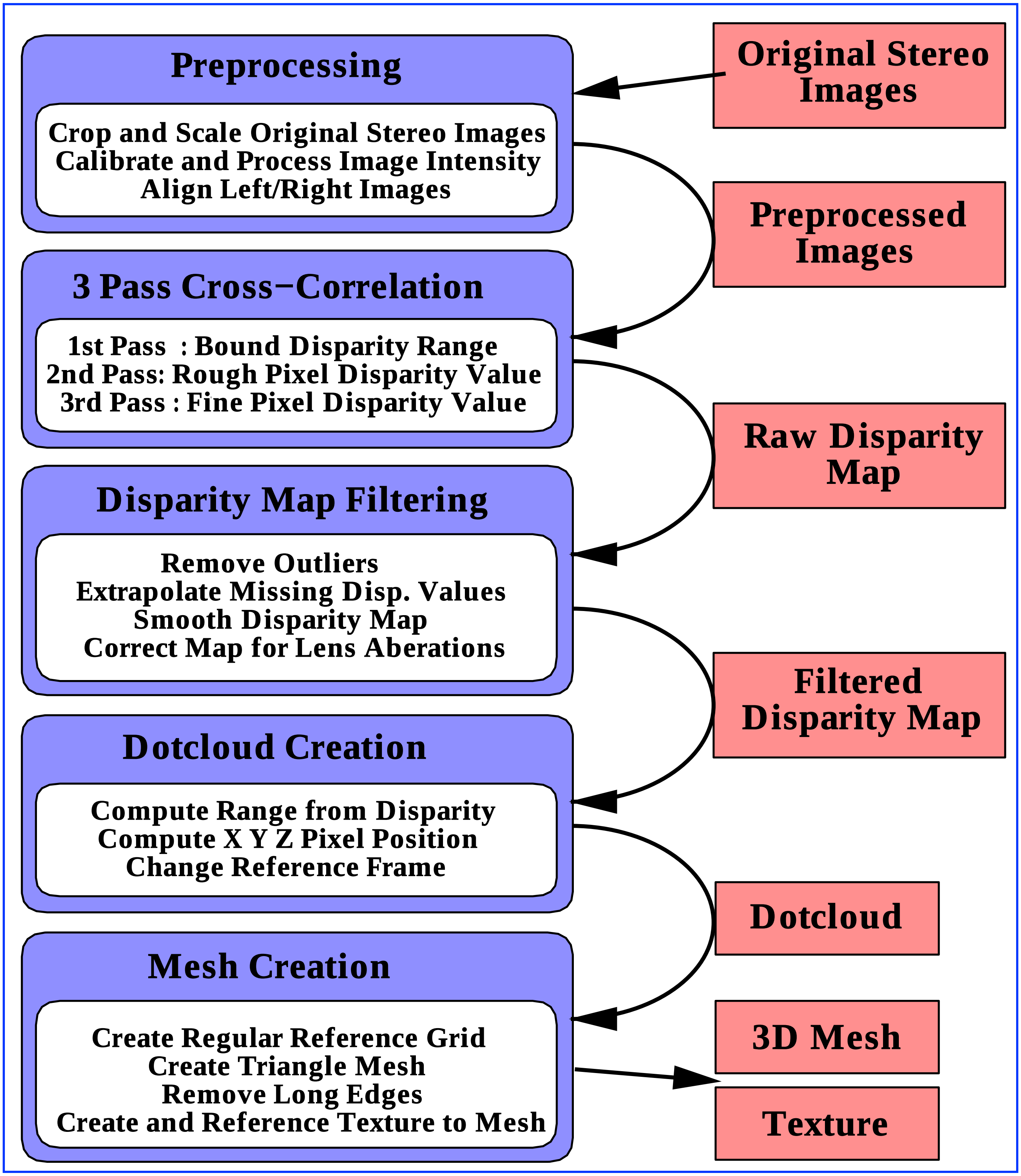
The Stereo Pipeline



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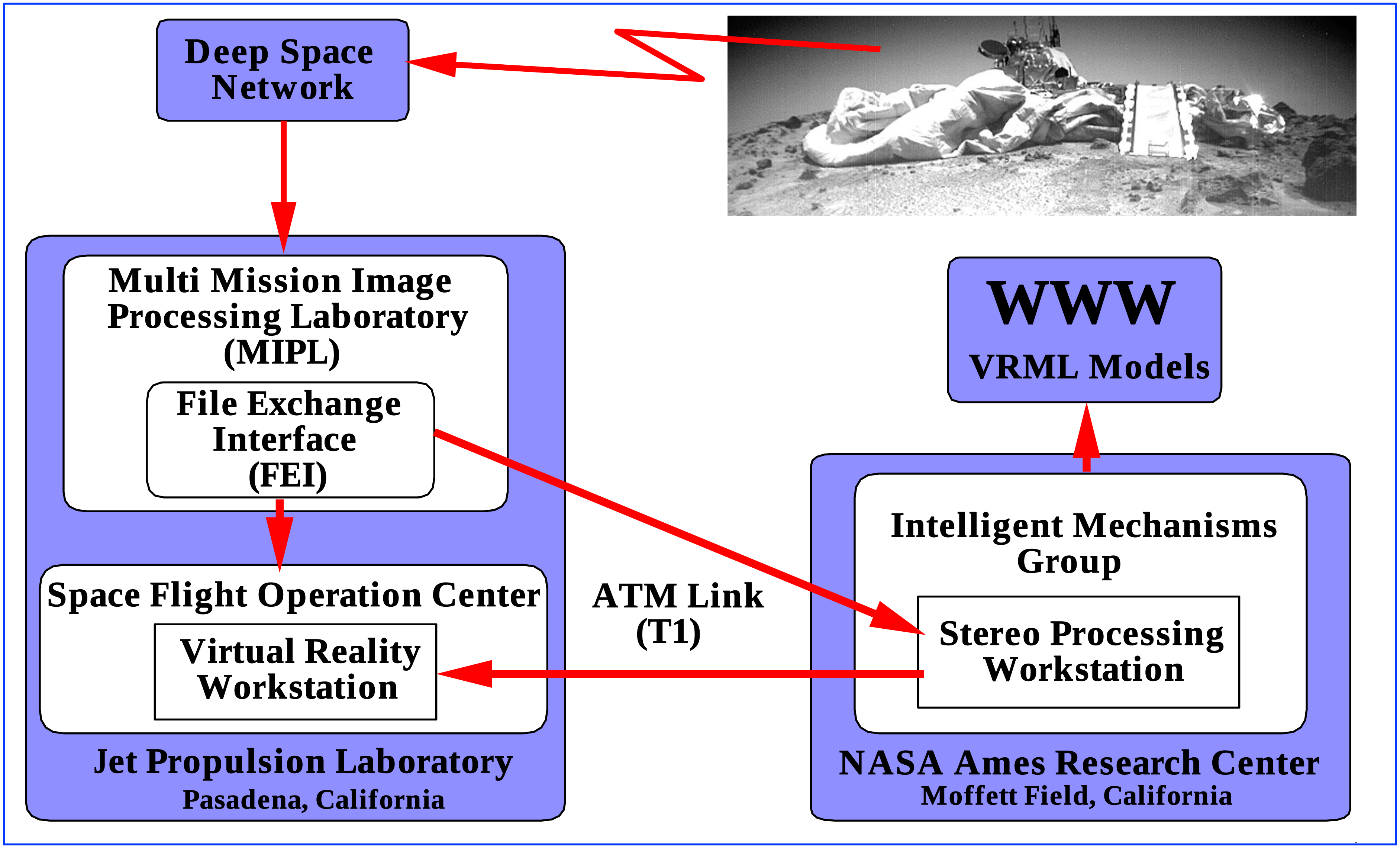
Network Data Flow



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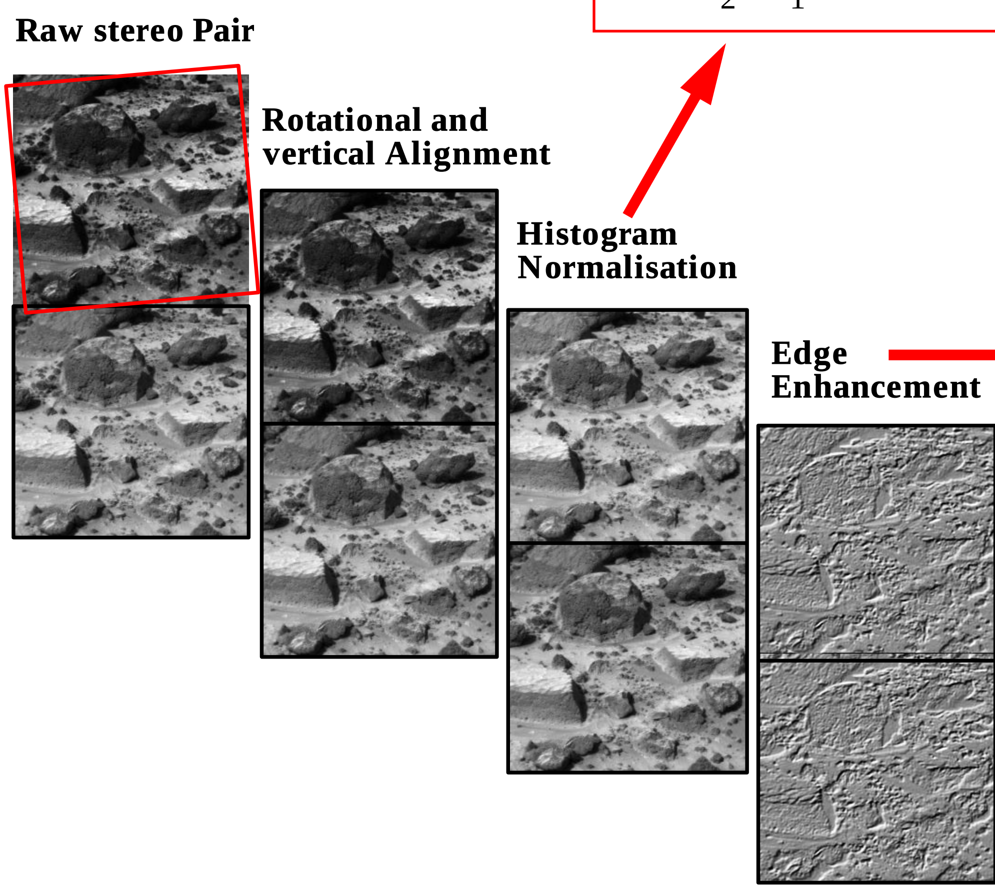
Preprocessing Step



$$I_o = \frac{G-2M}{T_2-T_1}(I_i - T1 + M)$$

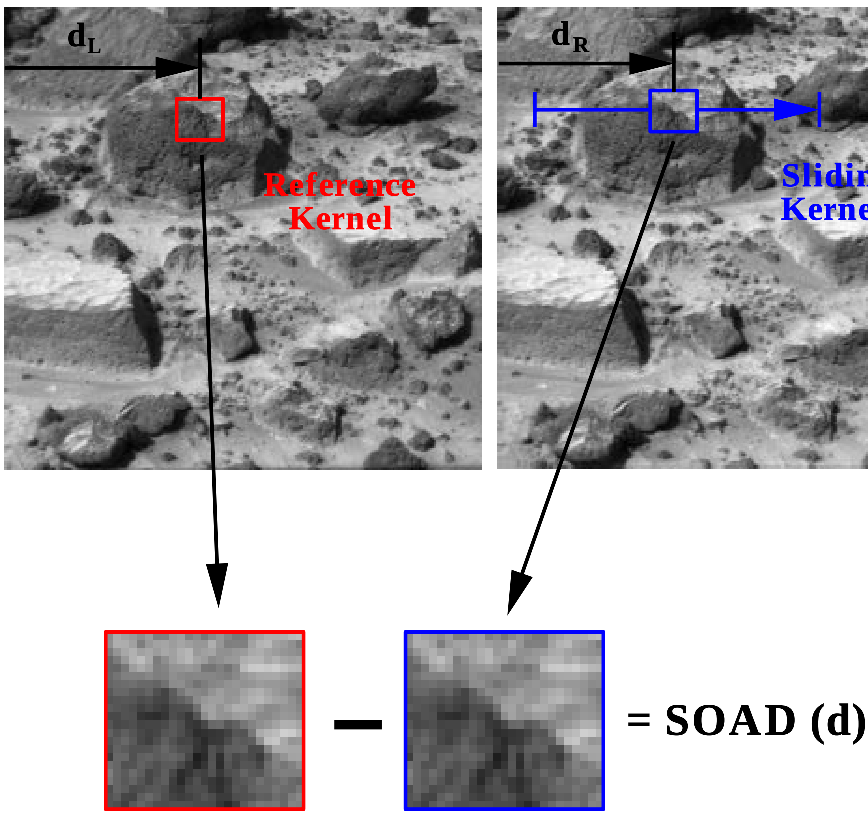
Where:

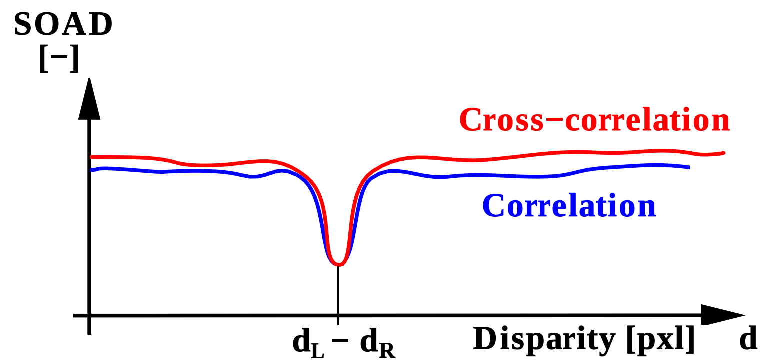
- Io : Output pixel intensity value [gray level]
- Ii : Input pixel intensity value [gray level]
- G : Number of gray levels [gray level]
- M : Margin [gray levels]
- T1 : Gray level under which 1% of the pixel values are.
- T2 : Gray level under which 99% of the pixel values are.

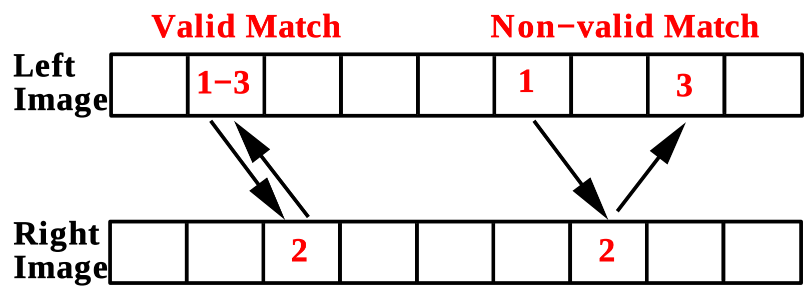
Convolution with:

$$B = \begin{bmatrix} -1 & -1 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix}$$

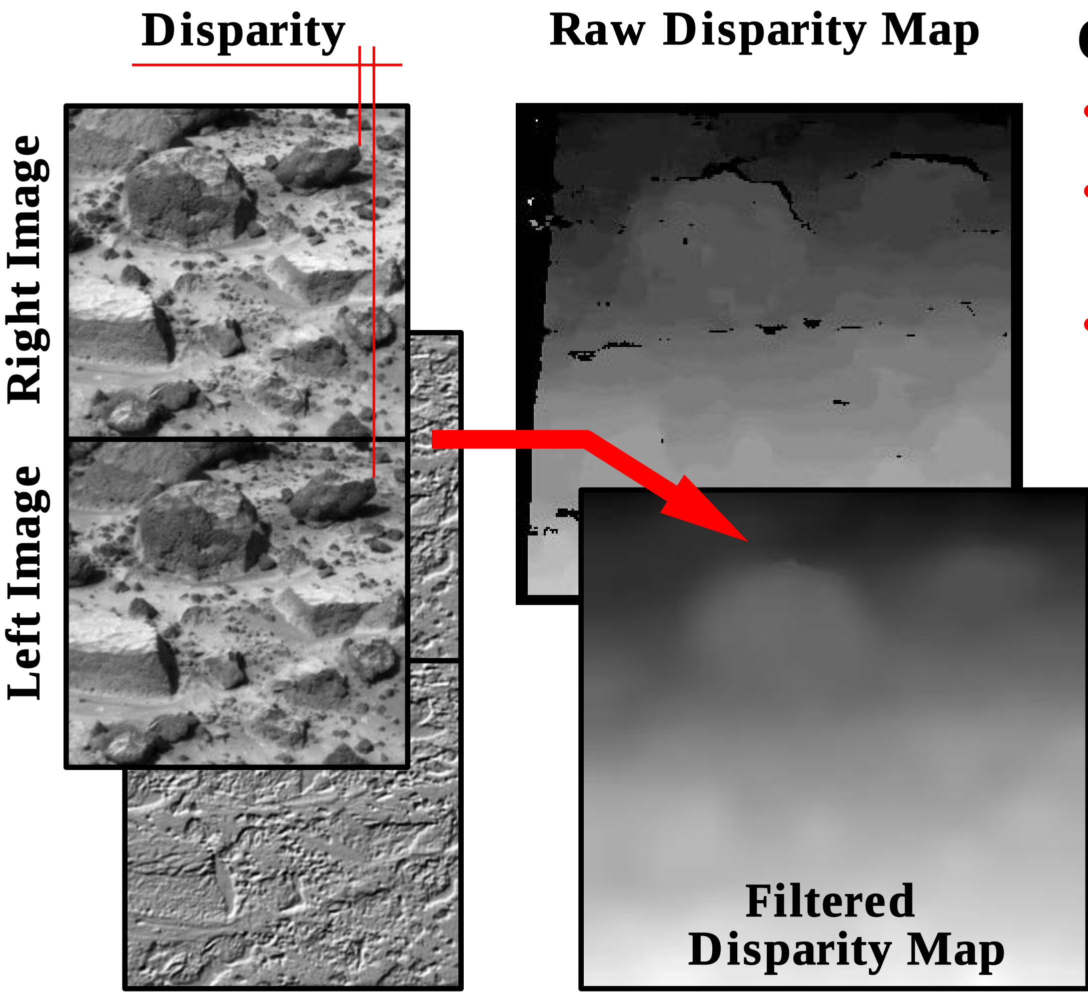
Correlation







Correlation and Disparity Map



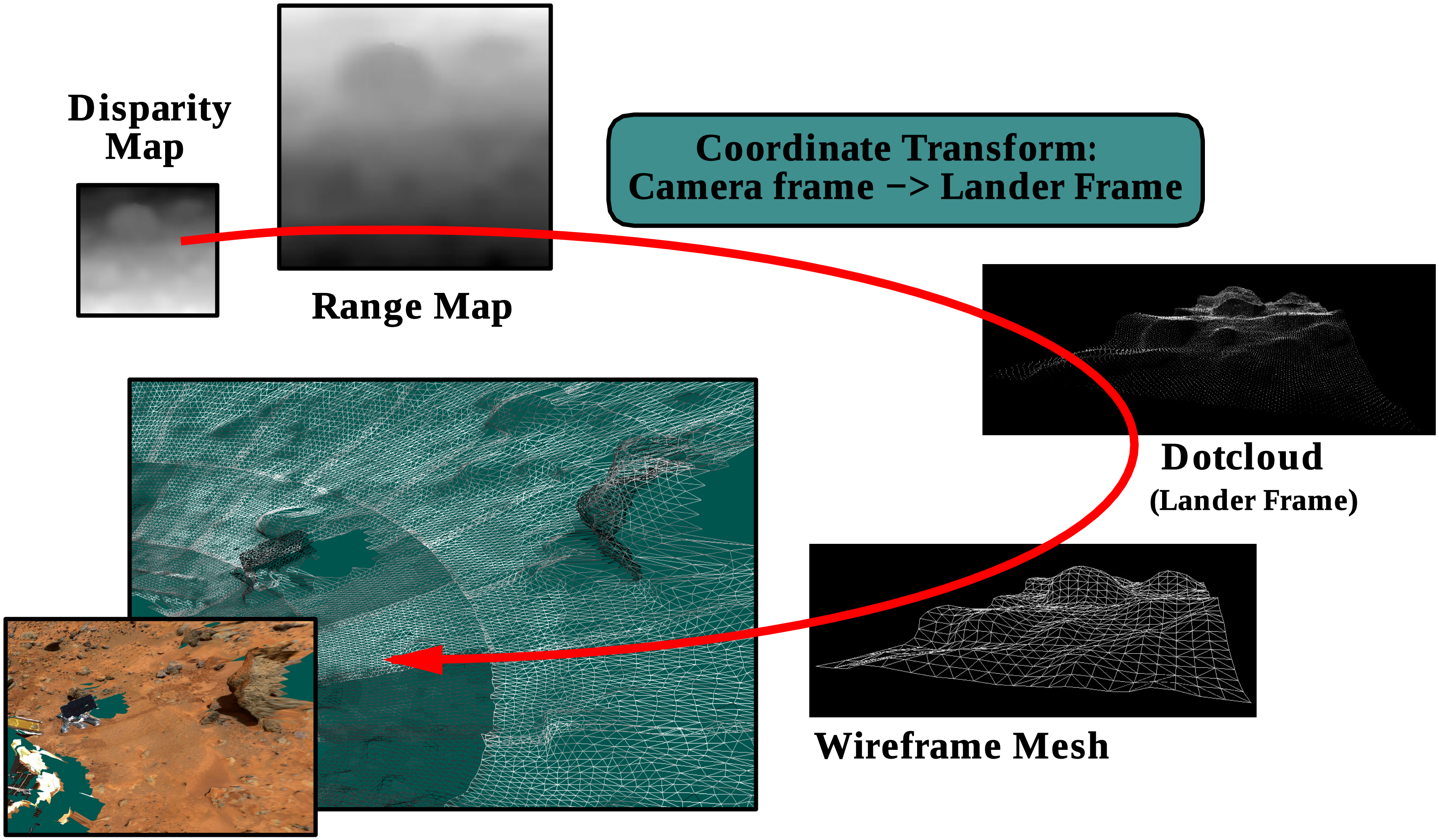
Correlation

- Texture-based correlation
- Sum-of-Absolute-Differences correlation algorithm
- Correlation and cross-correlation to remove wrong matches

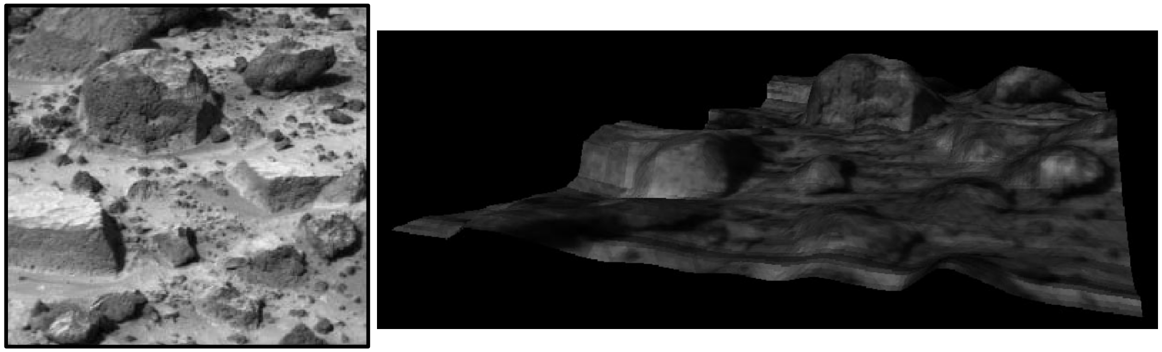
Filtering

- Subpixel approximation
- Outliers removal
- Adaptative gap filling
- Smoothing
- Lens abberation correction

Mesh Reconstruction

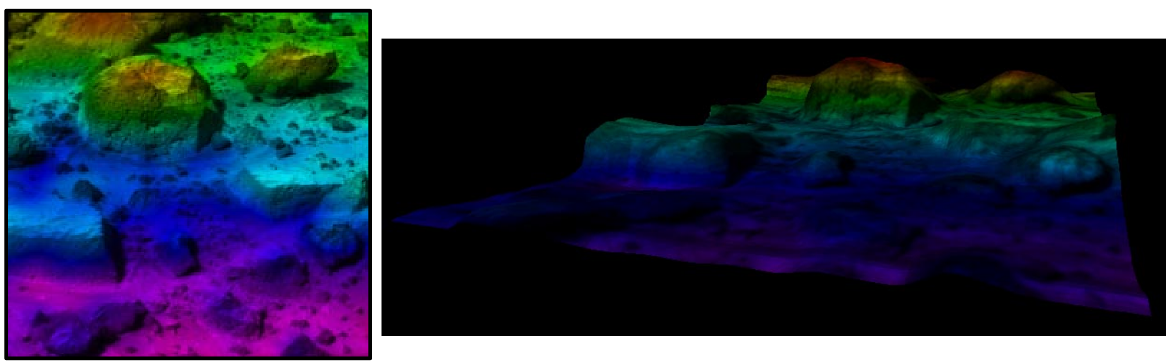


Texture Overlay



Original texture from the left image of the stereo pair (created automatically)

Color texture created manually from the Gallery Pan Images



Color coded elevation (mars local level) created automatically by the Stereo Pipeline

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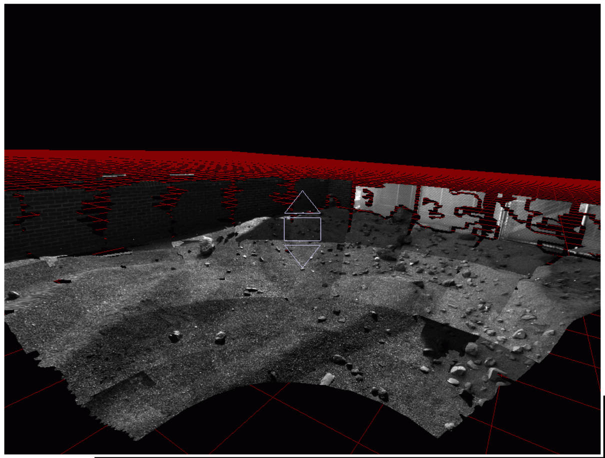
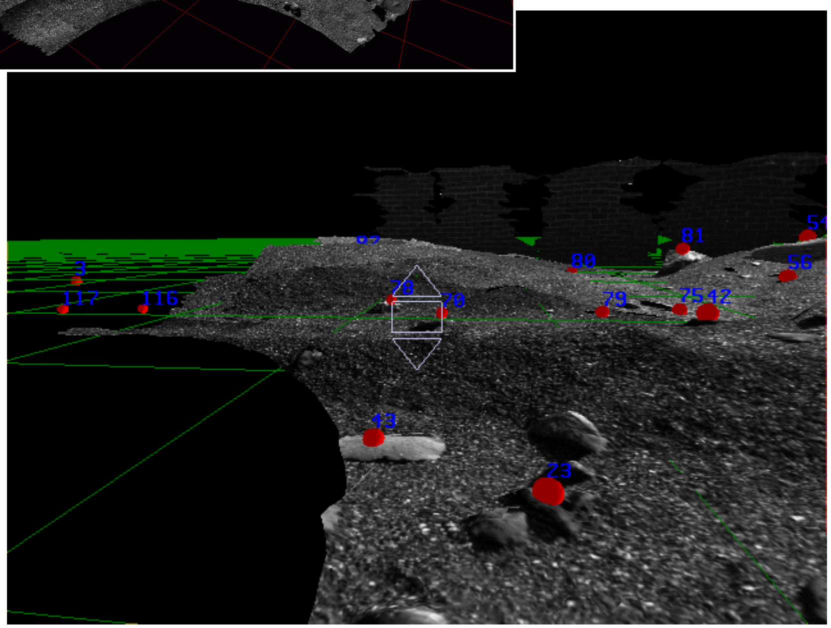
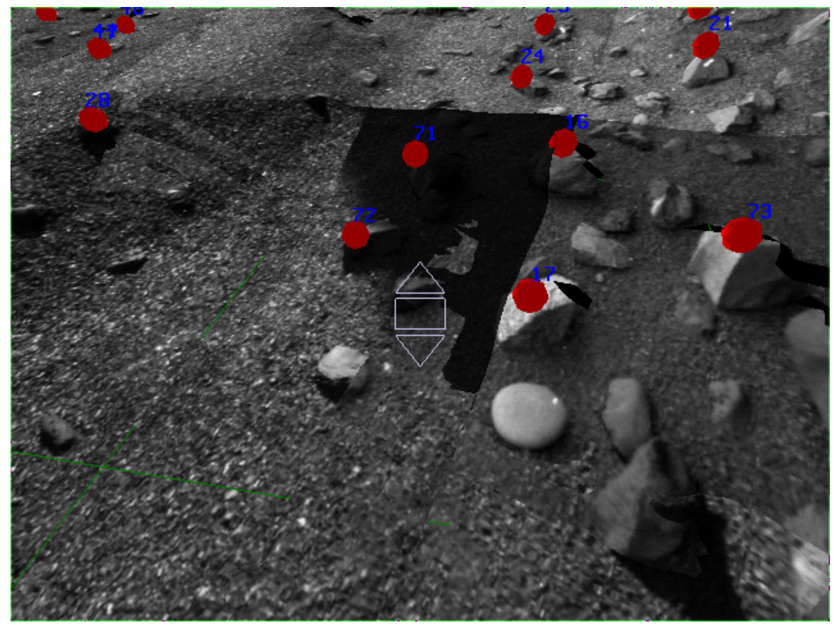
Calibration of the Terrain Models



- **Survey of 150 rock and ground feature positions in the Mars Garden at the University Of Arizona.**
- **Imaging and removal of the markers.**
- **Acquisition of the stereo datasets.**
- **Generation of the terrain models.**
- **Comparison between survey data and terrain models (51 positions compared)**





Calibration and Accuracy: Results

On a sample of 51 points ranging between 2 and 10 meters from the camera:

33% are within 1% of their surveyed position
89% are within 2% of their surveyed position
98% are within 5% of their surveyed position

Distance From Camera [m]	Average Error in Position
2-3	1.3%
3-4	1.7%
4-5	1.6%
5-6	2.6%
6-7	2.0%
7-8	3.2%
8-9	1.4%
9-10	3.2%

Factors affecting the Model accuracy

Terrain Related

- Nature and geometry of the terrain.
- Distance from the camera.

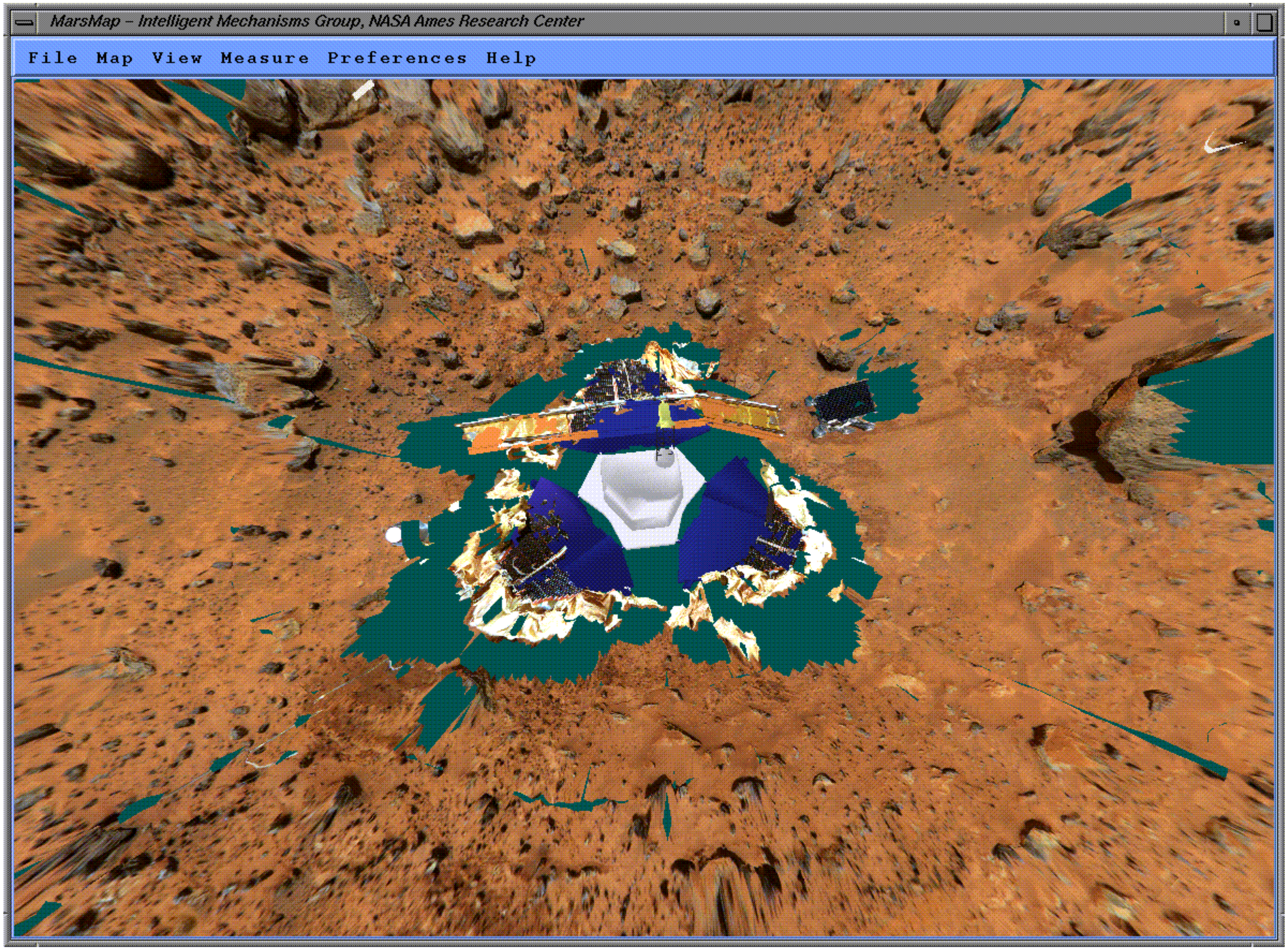
Data Related

- Pointing error of the camera
- Image scale
- Image quality and camera parameters characterization

Processing Related

- Correlation algorithm (pixel artifacts and kernel size)
- Meshing algorithm

VR Interface: Marsmap



Marsmap Utilization for MPF

Science Analysis

- Rock measurements
- Direction of wind streaks
- Topographical ridges and flow channels

Mission Operation and Planning

- Rover ramp deployment
- IMP pointing coordinates
- Long range Sojourner path planning

Data Archiving

- End of Day Rover positions
- Sojourner science experiments
- Rock locations and sizes

Outreach

- JPL-SFOF / NASA Ames demos and tours
- Virtual Mars on the World Wide Web (VRML)

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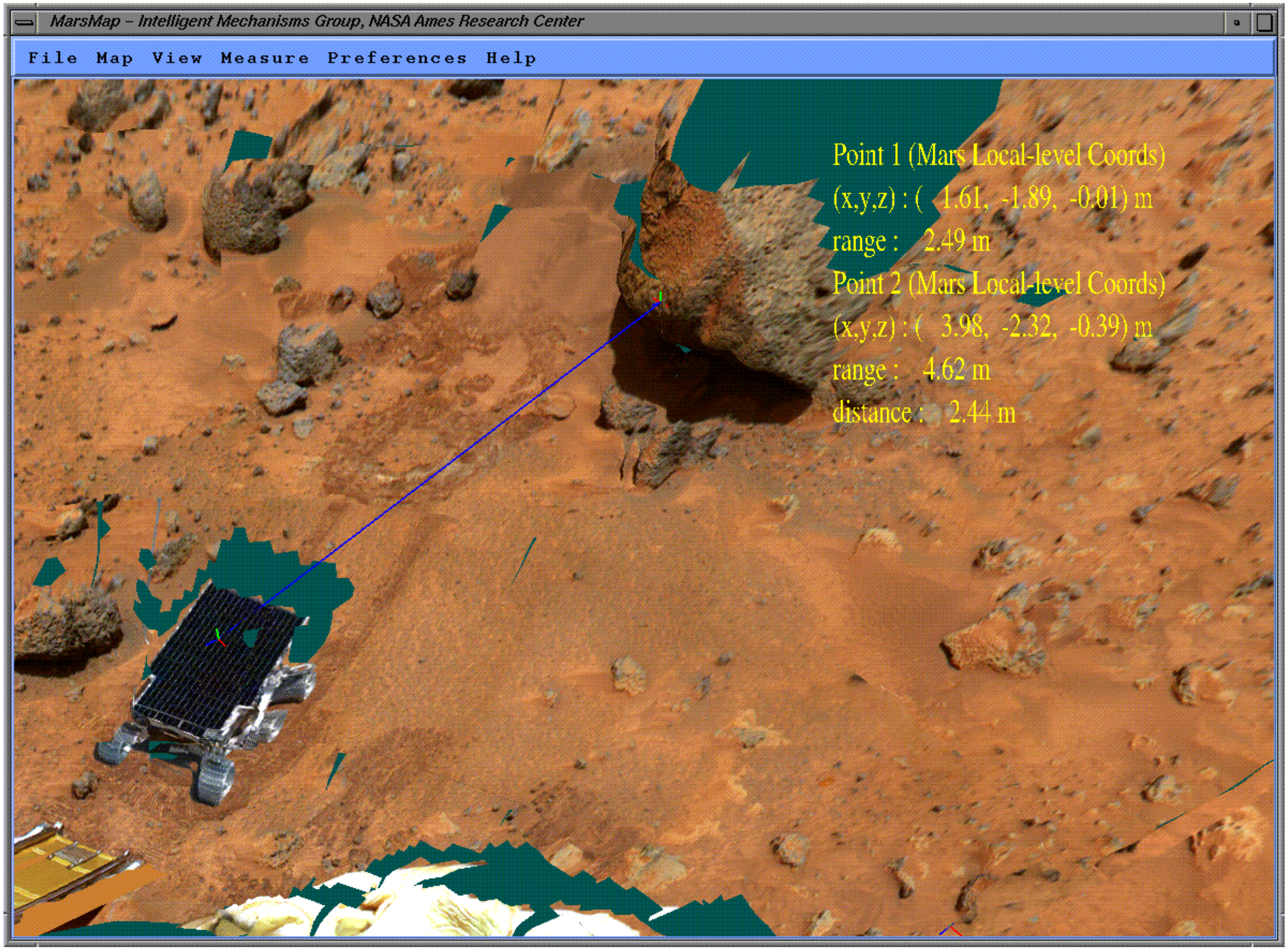
Measurements



Slope and Heading Angles

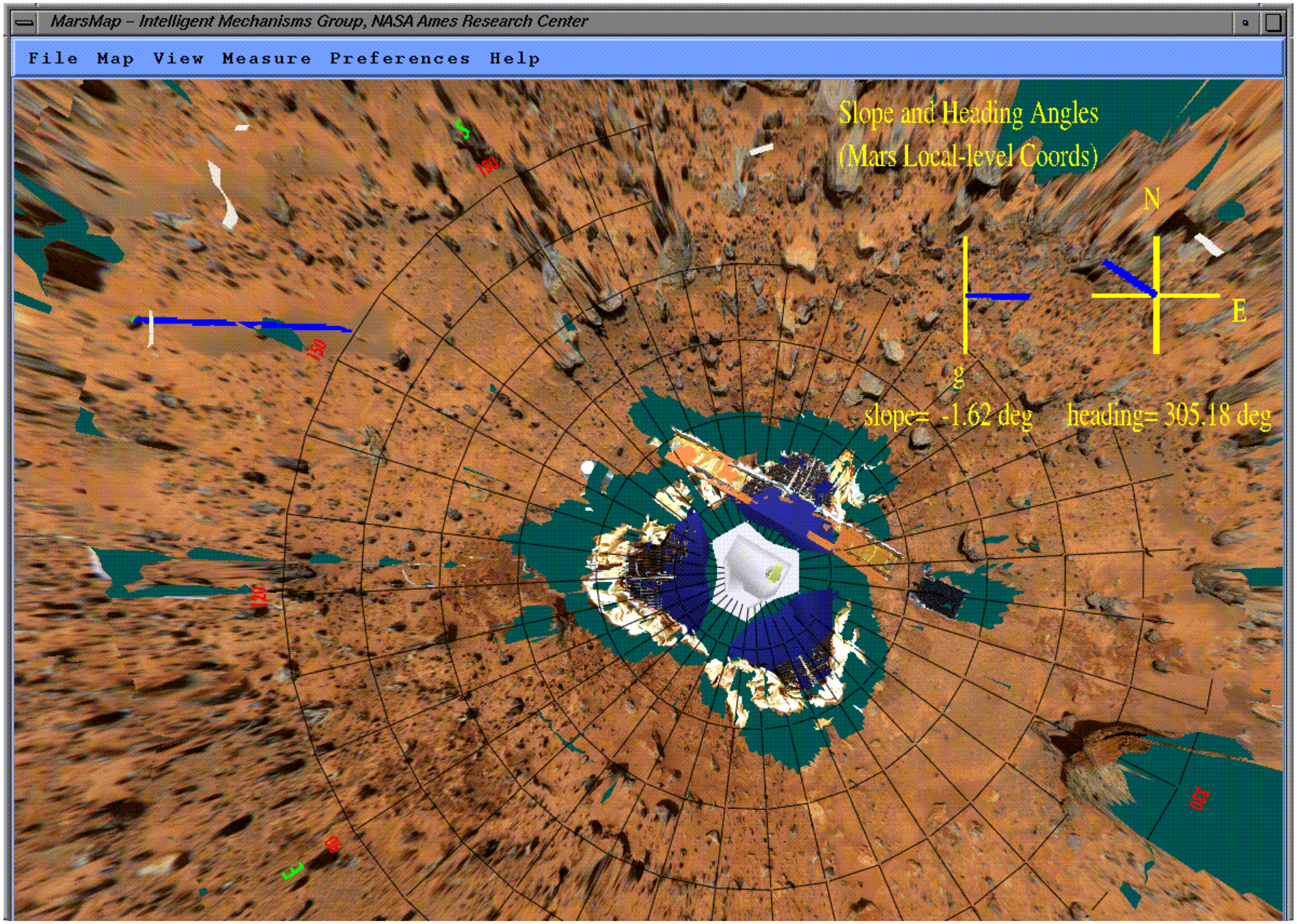
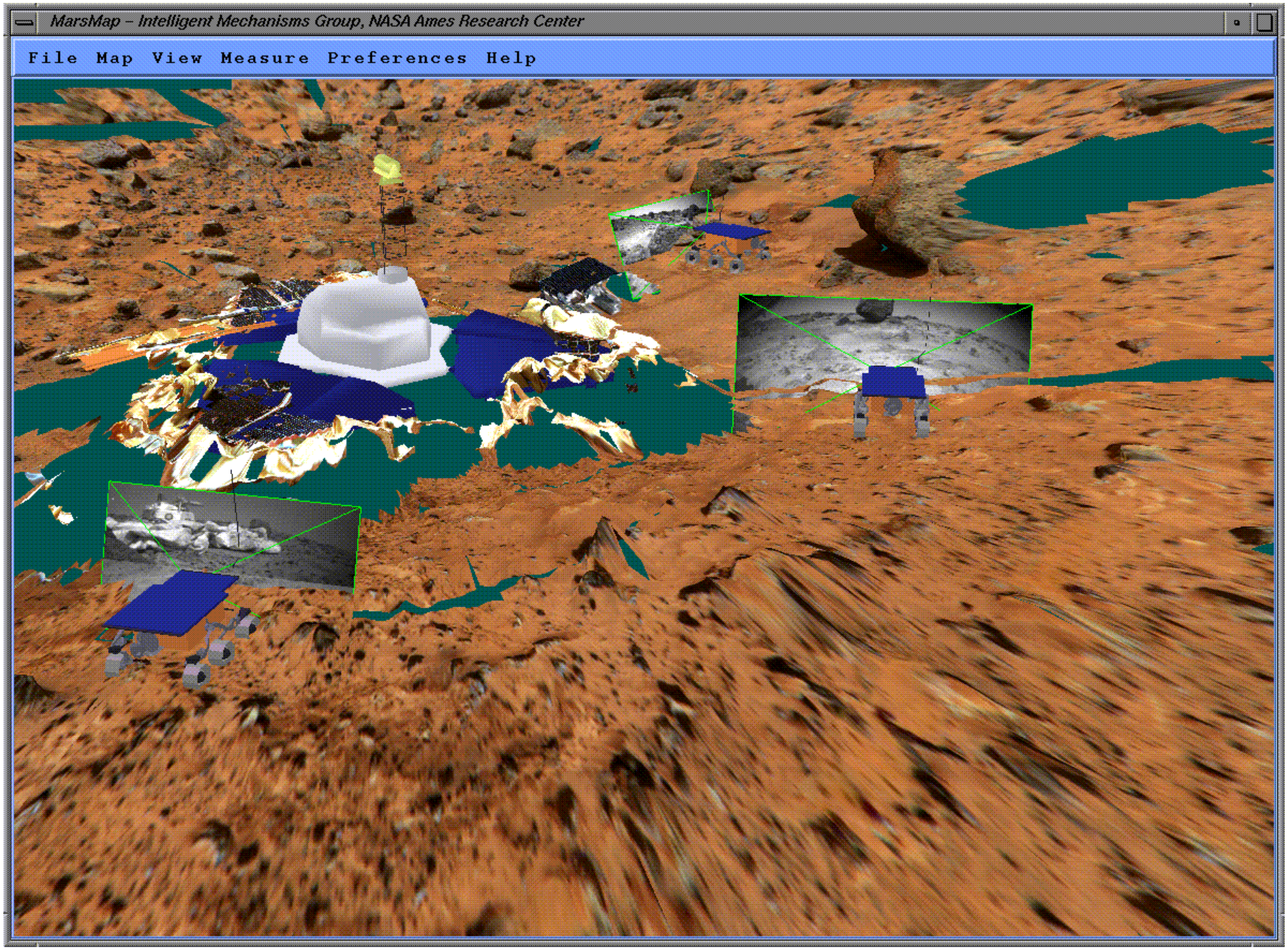


Image Billboards



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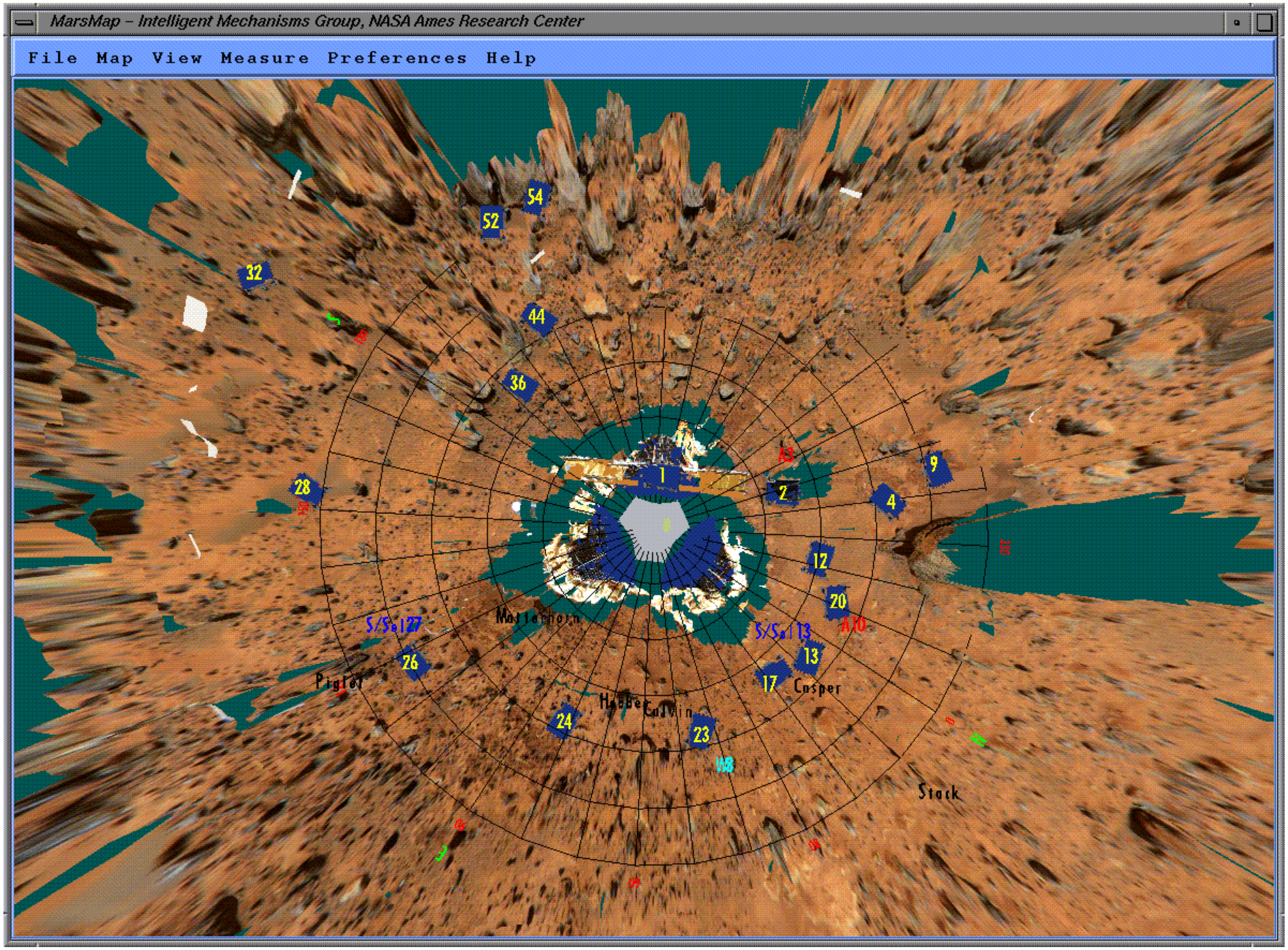
Data Archiving



Conclusion and Future Work

Conclusion

"IMG operational experience in Mars Pathfinder demonstrated that virtual reality interfaces displaying photo-realistic terrains were of tremendous value to scientists and rover operators"

- **Allow to clearly visualize all relevant information**
- **Facilitate rapid interpretation and decision making**

Technologies

- **Improve correlator**
- **Mesh optimization and levels of details**
- **Merging terrain models taken from multiple vantage points**
- **Development of science and visualization tools**
- **Development of simulation and archiving tools**

Ongoing and Future Projects

- **Pioneer (mapping Chernobyl unit 4)**
- **Mars 98**
- **Mars 01**