Optical Depth retrievals from and atmospheric correction of HRSC stereo images of Gusev crater:

validation by comparing with Spirit's ground truth

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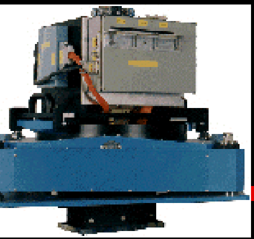
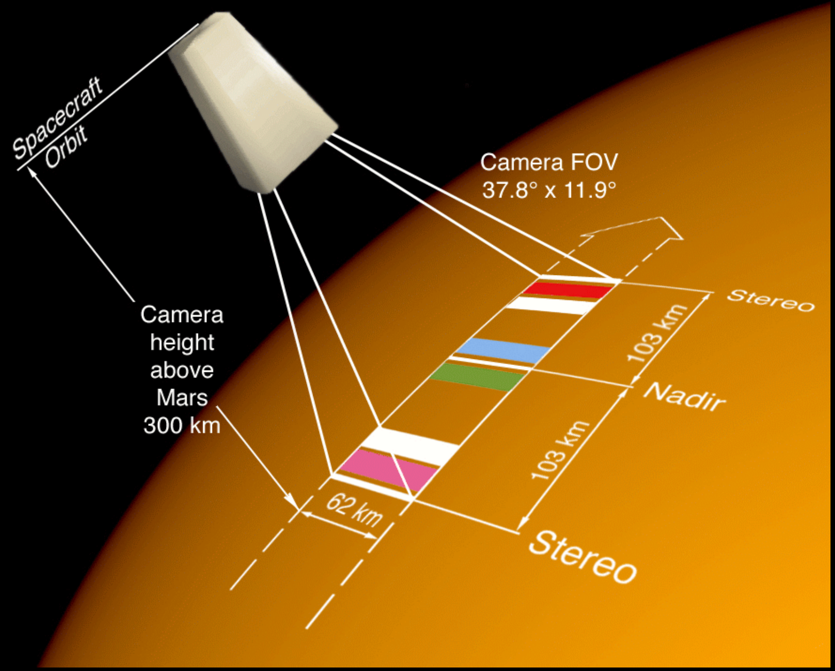
1. Retrieval of atmospheric optical depths with the <u>stereo method</u> from HRSC stereo images

2. Atmospheric correction

- Observations from orbit 24 (Jan 16 2004)
- Comparison with Spirit's ground truth



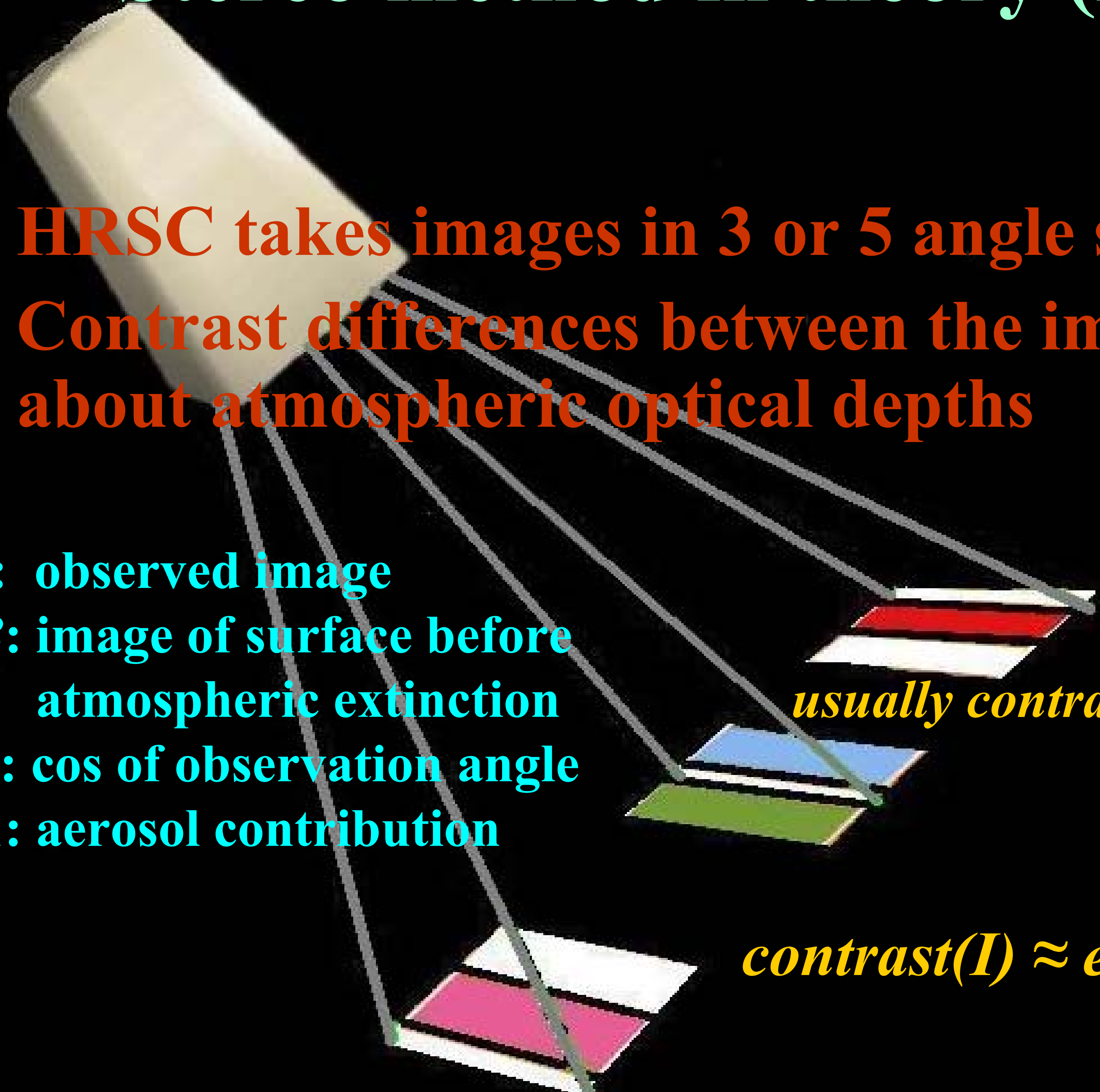
DLR's HRSC Stereo Camera



Filters: 5 panchromatic and 4 color	
Nadir	**675 (+- 90) nm**
Outer stereo (2)	**675 (+- 90) nm**
Inner stereo (2)	675 (+- 90) nm
Blue	440 (+- 45) nm
Green	530 (+- 45) nm
Red	750 (+- 20) nm
Near Infrared	970 (+- 45) nm
Radiometric resolution	8 bit
Active pixels per sensor	5184
Operational lifetime	>4 years
Typical operations duration	4-30 min
Stereo angles [degrees]	-18.9, -12.6, 0, +12.6, +18.9
Pixel on the ground	12 x 12 m^2 at 300 km altitude
Swath width on the ground	11.9 degrees or 62.2 km at 300 km
SNR	blue >40, rest >80, panchrom. >>100
Coverage first Martian year	50% at 15m/pix panchromatic in nadir
Typical image	62 x 330 km^2

Stereo method in theory (I)

- **HRSC takes images in 3 or 5 angle stereo**
- **Contrast differences between the images tell about atmospheric optical depths**



I: observed image
B: image of surface before atmospheric extinction
μ: cos of observation angle
A: aerosol contribution

$$I=B*e^{-\tau/\mu}+A$$

usually contrast in A is small ➔

$$\text{contrast}(I) \approx e^{-\tau/\mu}\,\text{contrast}(B)$$

Stereo method in theory (II)

$$\left.\begin{array}{l}\text{contrast}(I_1) \approx e^{-\tau/\mu_1} * \text{contrast}(B_1) \\ \text{contrast}(I_2) \approx e^{-\tau/\mu_2} * \text{contrast}(B_2)\end{array}\right\}$$

If contrast(B_1) ≈ contrast(B_2) then

$$\tau \approx \frac{\mu_1 \mu_2}{\mu_1 - \mu_2} * \ln\left(\frac{contrast(I_1)}{contrast(I_2)}\right)$$

Default nadir pointing: $\frac{\mu_1 \mu_2}{\mu_1 - \mu_2} \approx 17.6$ **Factor is determined by 18.9° stereo angles**

In these images HRSC is looking sideways by 14—32°

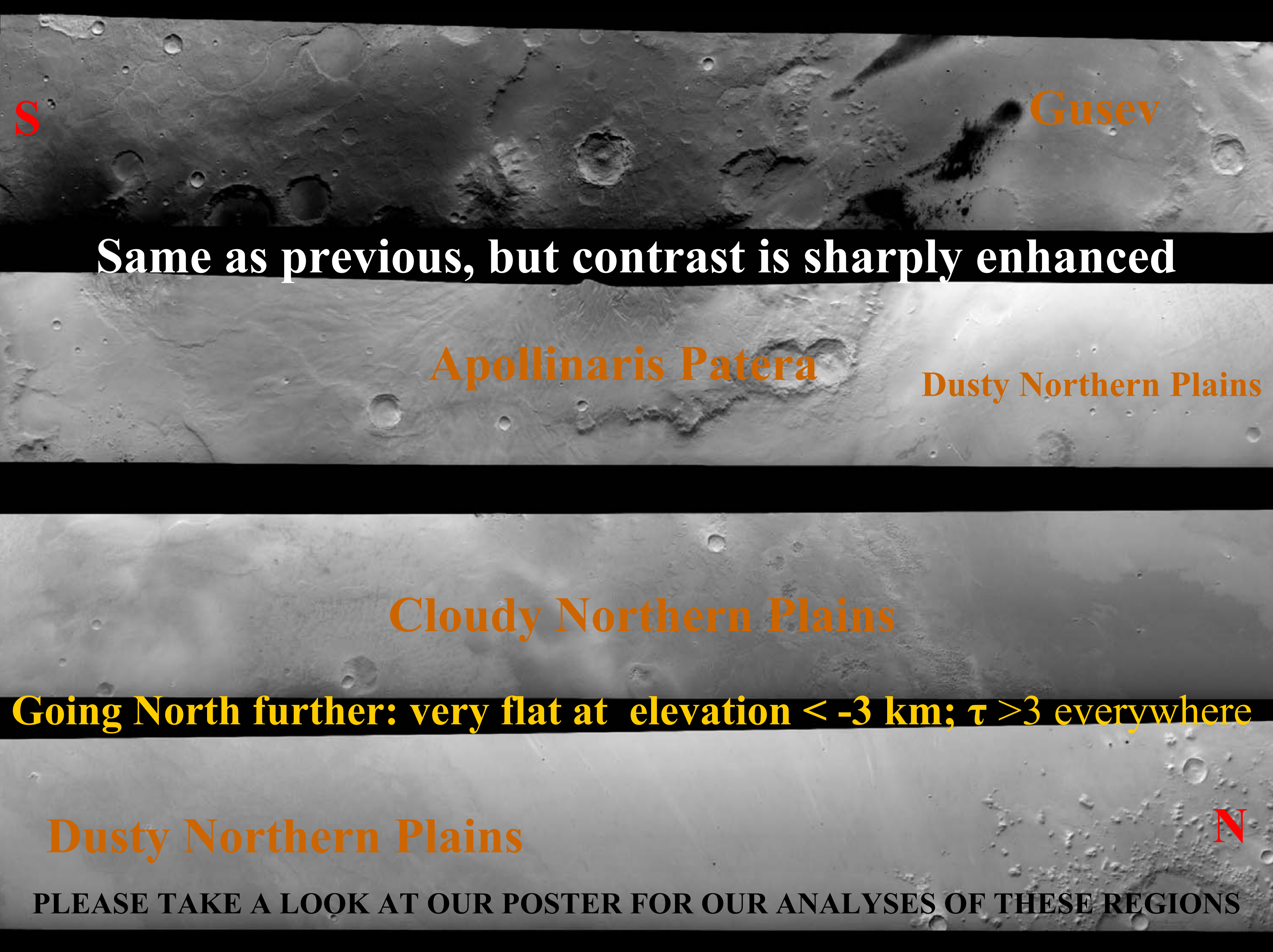
➔ here the factor varies between 12 and 14

Theory versus reality

Usually contrast(*B1*) ≠ contrast(*B2*) since hills and holes, and especially shadows look different from different viewing angles.
I.e., perspective has a big impact on errors

1) **Measure contrasts from images in which perspective effects are as small as possible… ➔**
   Fit images onto Digital Terrain Model ➔ ortho-images
2) **…in way that is not too sensitive on such perspective effects ➔ Use difference between brightest and darkest pixels to quantify contrasts**

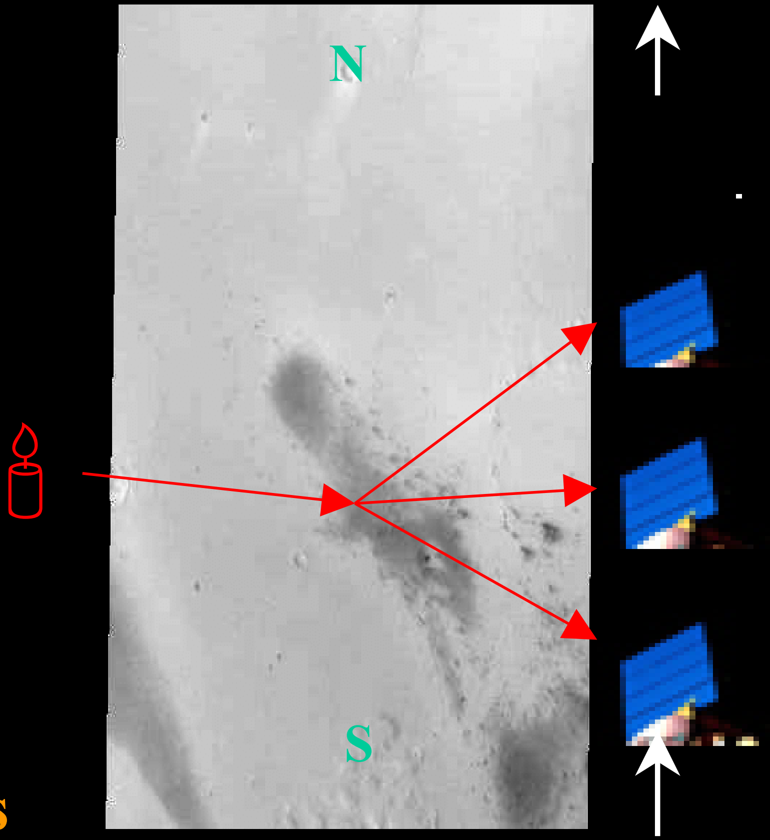
Orbit 24 nadir image

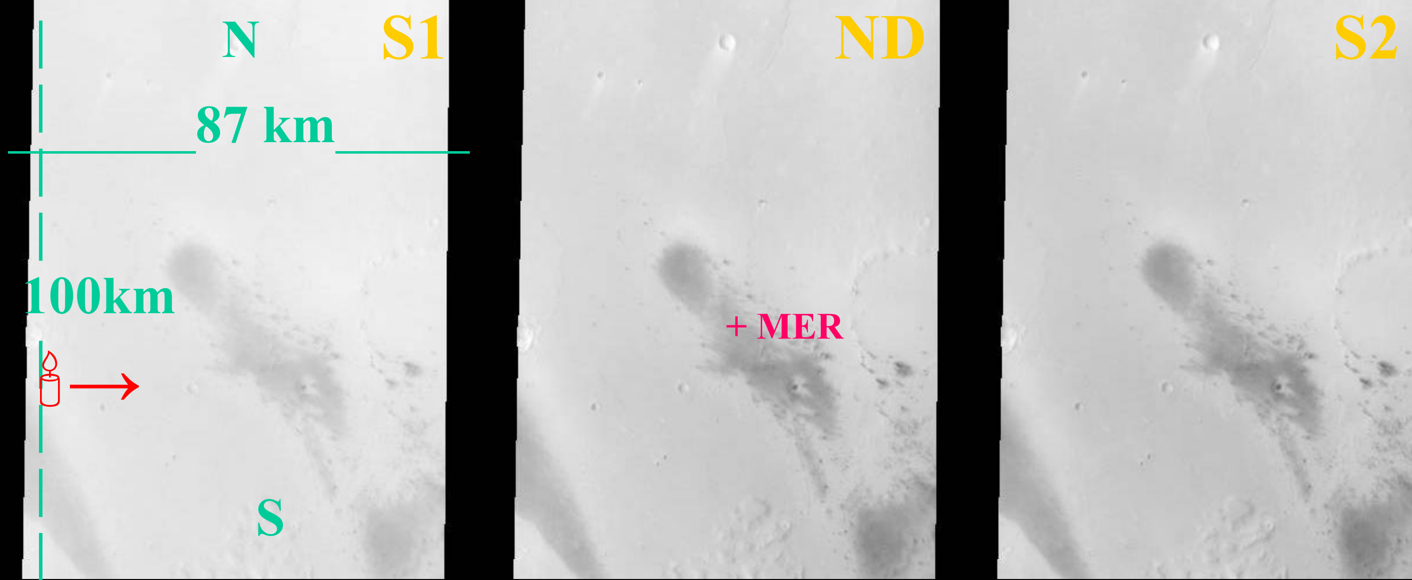

S
Gusev
Same as previous, but contrast is sharply enhanced
Apollinaris Patera
Dusty Northern Plains
Cloudy Northern Plains
Going North further: very flat at elevation < -3 km; τ >3 everywhere
Dusty Northern Plains
N
PLEASE TAKE A LOOK AT OUR POSTER FOR OUR ANALYSES OF THESE REGIONS

Validate the stereo method with Spirit's ground truth

Geometry of observations is quite favorable

- **Very flat region**
- **Rich in contrast due to dark patches on crater floor**
- **Camera is looking sideways ➔ larger difference between optical paths of 'nadir channel' and stereo channels than with default nadir pointing**
- **Solar illumination almost perpendicular to the flight direction ➔ not much change in phase angles between the channels**



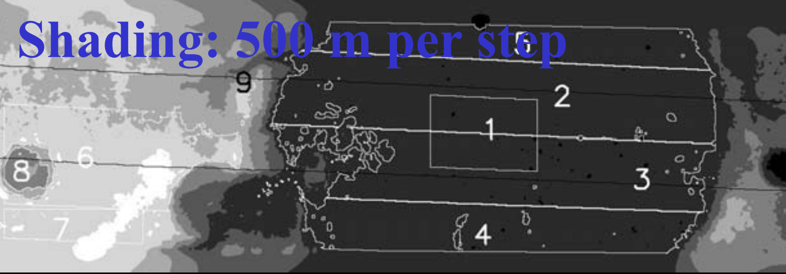


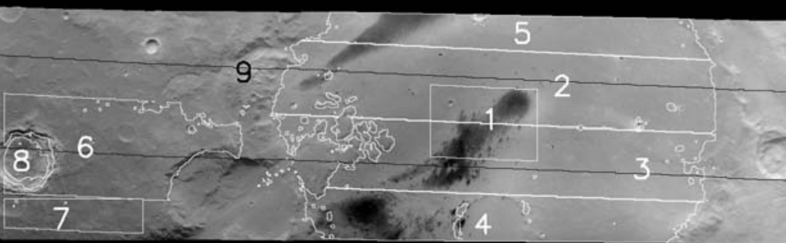
Reduce spatial resolution to improve intensity resolution

- Original pixels --- roughly 20—40 meter/pixel
  - The stereo method does not need such high spatial resolution
  - On the other hand, only 30—40 intensity bins are used ➔
  - Very crude intensity distribution, not good for stereo method
- We used pixels rebinned at 200 meter/pixel
  - These have less spatial, but better intensity resolution

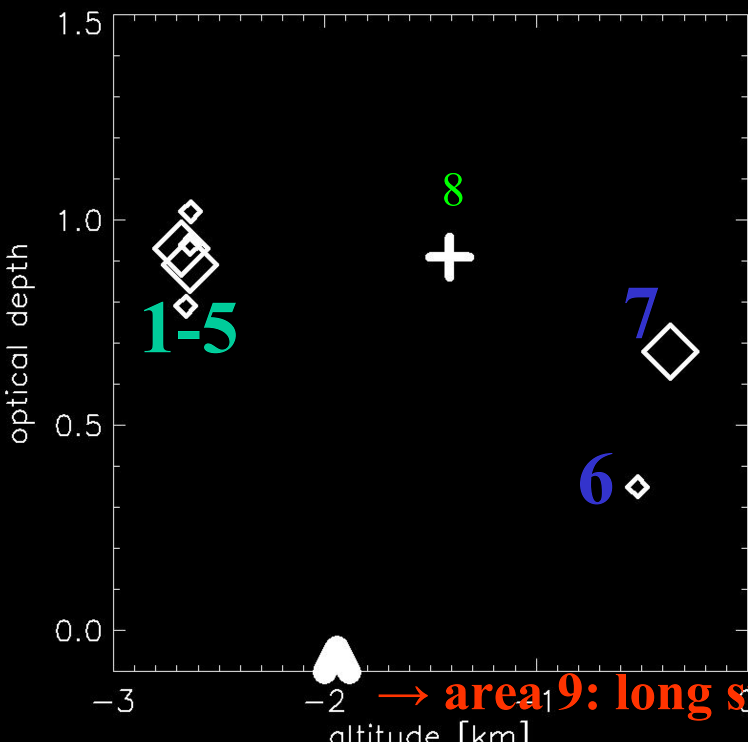
In and around Gusev

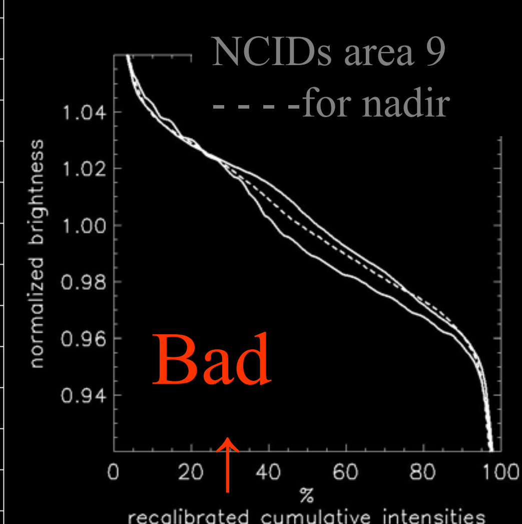
- Gusev, stereo method : 0.91 ± 0.04
- Gusev, Spirit's 'ground truth': 0.87—0.89
- Very good result for the floor of Gusev crater

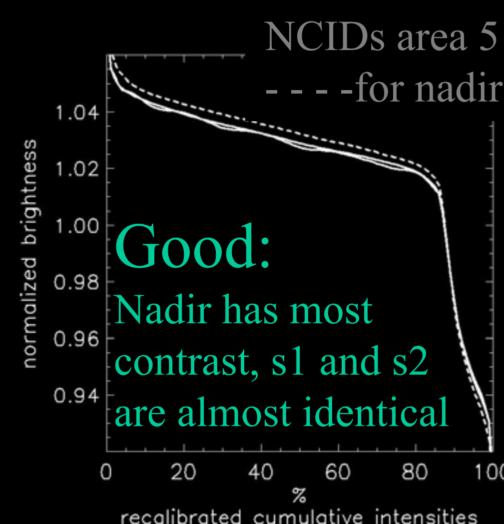




- However, optical depth depends on altitude!
- Large variations in altitude within an analyzed area often prohibit proper retrieval
- Use so called 'Normalized Cumulative Intensity Distributions' (=NCID s) to judge the quality of the retrieval
- Best if curves for S1 and S2 are nearly identical



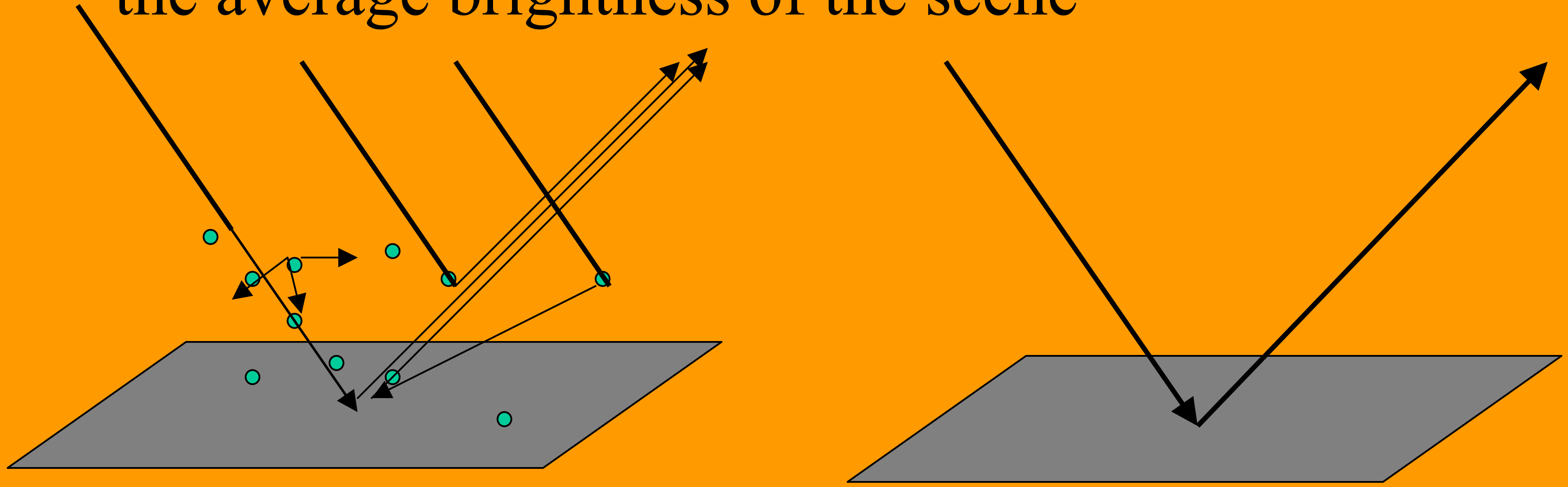




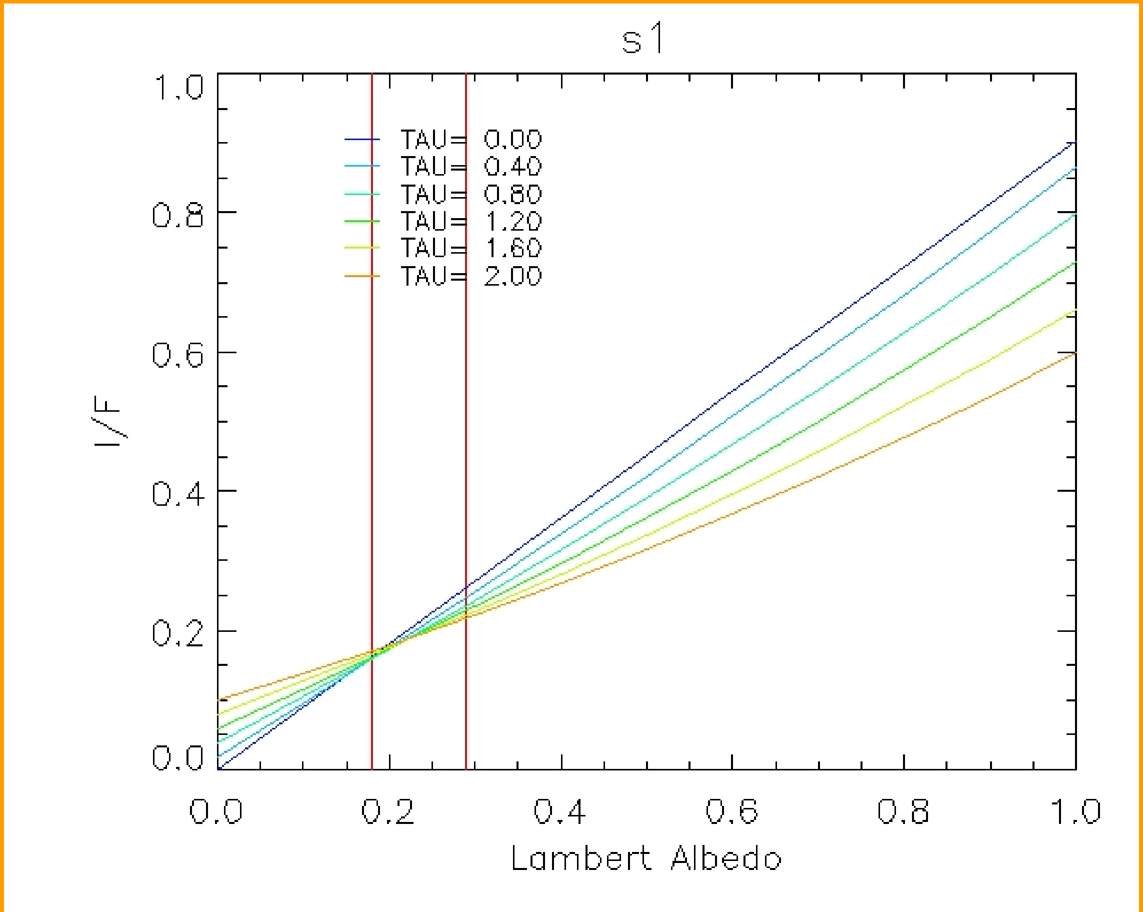
→ area 9: long strip with altitude differences > 2 km gives tau < 0

Atmospheric correction

- **What is atmospheric correction? ➔**
  - Make images that show Mars as it would look without its atmosphere
- **Simplistic correction: multiply contrasts with** $e^{\tau/\mu}$
  - Rather inaccurate, since the atmosphere can change the average brightness of the scene



Model I/F at the Top of Atmosphere with SHDOM



Surface: Lambert

Atmosphere: only dust

dust scattering properties: from IMP

Radiative transfer model: SHDOM

Geometry:

observation of Gusev

i = 25.34

e =31.68

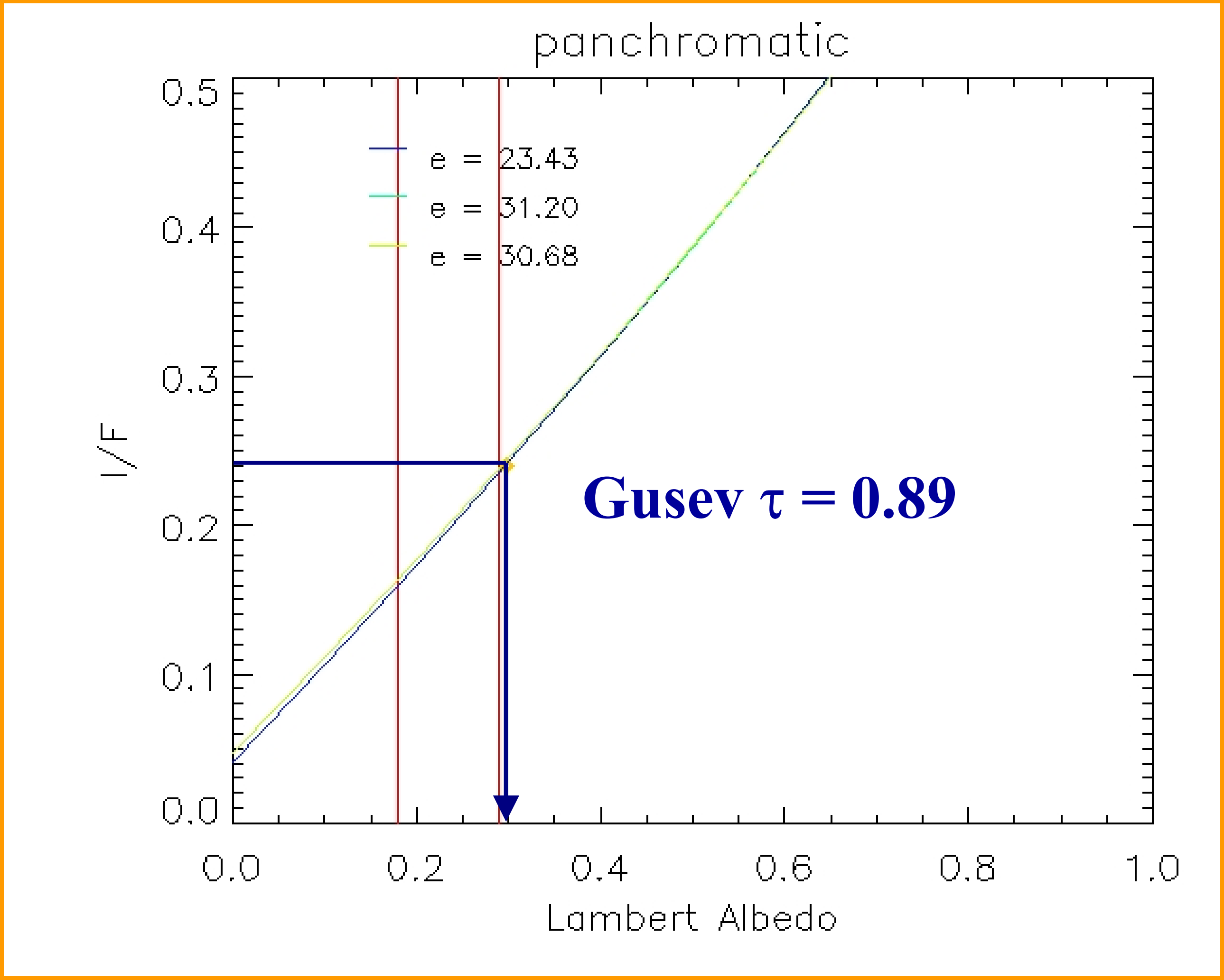
g =51.96

Atmospheric effect:

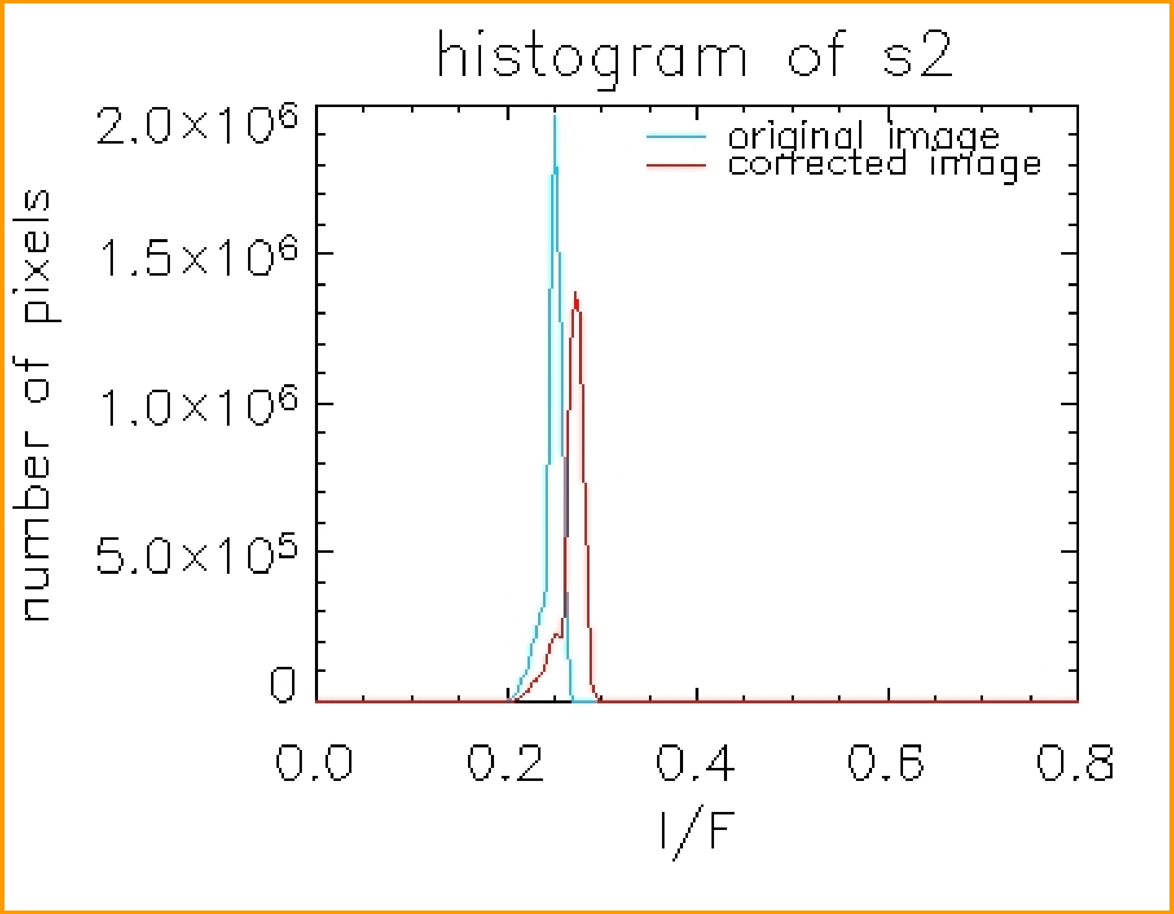
- **Bright regions (albedo >~ 0.22) become darker**
- **Dark regions (albedo <~ 0.22) become brighter**

Example of Atmospheric Correction:

(Lambert approximation)



Result, histogram



Corrected image:

•Dark surface has Albedo 0.2

•Bright surface has Albedo 0.3

•Good agreement with ground truth by Spirit

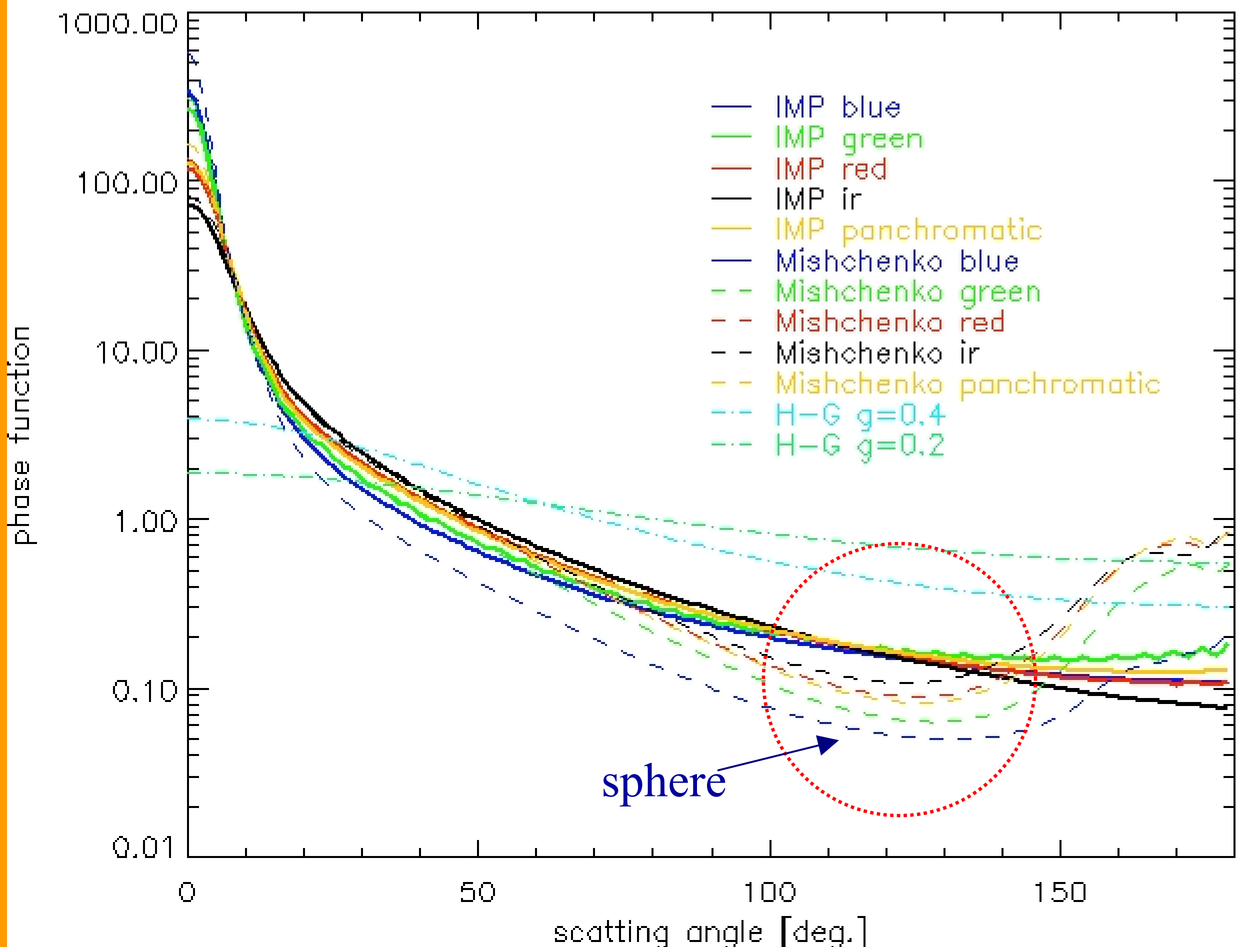
Corrected Color Image

Original RGB color

Corrected RGB color

What makes the atmospheric Correction difficult?

Phase functions of various types of Aerosols



reff = 1.6 mm Observation vs. Mie calculation of spherical particles

Not well known for Martian aerosols:

- **Phase function**
- **Single scattering albedo**
- **The shape of dust particles, but we do know that they are not spherical**
- **The vertical distribution of aerosols**

Summary

STEREO METHOD

- **Careful consideration of topography is crucial**
- **For most flat regions the stereo method works,**
  - **If…there is enough contrast**
- **Check input carefully, use NCIDs to judge usability of regions**

ATMOSPHERIC CORRECTION

- **Atmospheric correction is performed with**
  - **Lambertian surface**
  - **Dust scattering properties from IMP data**
- **Martian atmosphere brightens or darkens the surface**
- **Improvements of atmospheric correction**
  - **Vertical distribution of aerosols**
  - **Scattering properties of non-sphere dust particles**
  - **More realistic surface reflectance model**

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and the HRSC and MER science teams

Abstract:

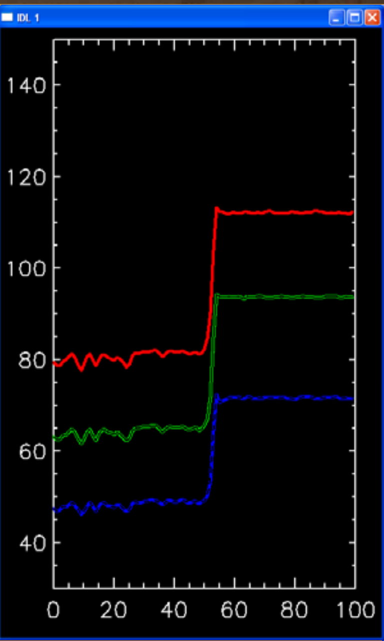
A primary task for the Mars Express orbiter is to map Mars in high-resolution and in stereo with its High Resolution Stereo Camera (HRSC). The Martian atmosphere contains variable amounts of aerosols that scatter light and influence the images. For many applications, analysis of HRSC images requires atmospheric correction. Minimum required inputs for such a correction are the optical depth of the atmosphere and the single scattering properties of the aerosols.

Optical depths can be retrieved from stereo-images with the so-called 'stereo-method'. This method estimates optical depths by analyzing how contrasts differ between stereo images. Software for using the stereo-method has been developed at the Max-Planck-Institute for Solar System Studies (MPS) in Katlenburg-Lindau, Germany. The method uses map-projected ortho-stereo-images and complementary data on the imaging geometry from photogrammetric software developed at DLR. Once an optical depth is known, and a phase function is chosen, we can correct for atmospheric effects with other programs developed at MPS, such a MPAE_ATM_DUST.

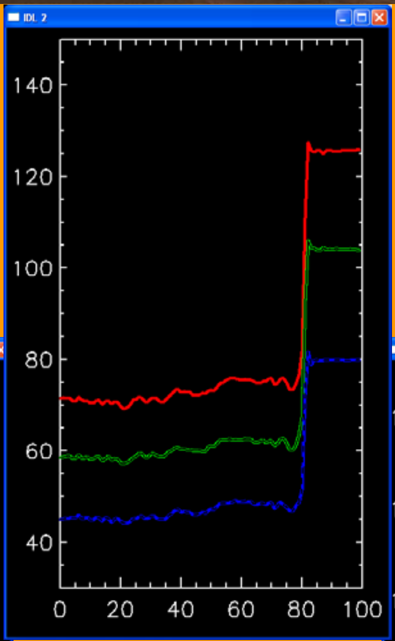
For validation, we compared optical depths retrieved from HRSC stereo images of Gusev crater taken on January 16.04 with in-situ measurements by Spirit, the rover that landed in this crater. That day Spirit measured the local optical depth at 0.87-0.89 by looking up at the Sun. From HRSC images, we estimated 0.86 ± 0.08 for a small region around the landing site, and 0.91 ± 0.04 for the full crater. Both values are in good agreement with Spirit's ground truth. Spirit landed in a region that displays considerable contrast, which improves the accuracy of the retrieval considerably. In addition, very careful consideration of topography proves crucial since the retrieved optical depths, and especially their errors, depend very strongly on altitude variations within the analyzed field.

We calculated a corrected image of a region around the landing site, using an optical depth of 0.89 and an aerosol phase function as derived from Mars Pathfinder data. We find reasonably good agreement with local measurements from Spirit.

Aerosols, do they brighten or darken the view? (I)



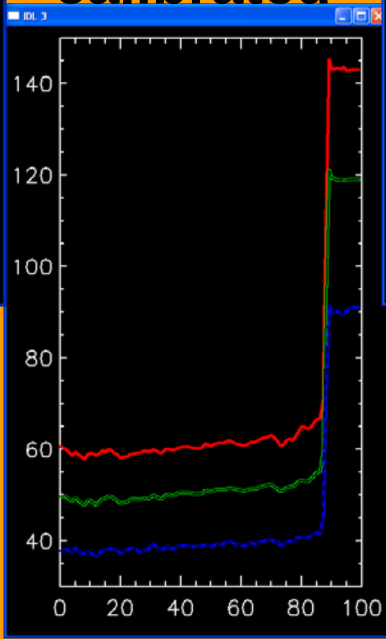
Meridiani, 360° view. JPEG image is <u>not</u> calibrated



Towards the Sun
scene brightens with distance
Other directions
little or no impact ➔
<u>strong forward scattering</u>

How much?
Educated guess:
up-to 3--5%?

I'll do this properly once I have calibrated images



Horizon:
5—6 km?
$\tau_{\downarrow} \approx 0.7$ ➔
$0 < \tau_{\rightarrow} < \sim 0.5$