Mars Optimized Solar Cells

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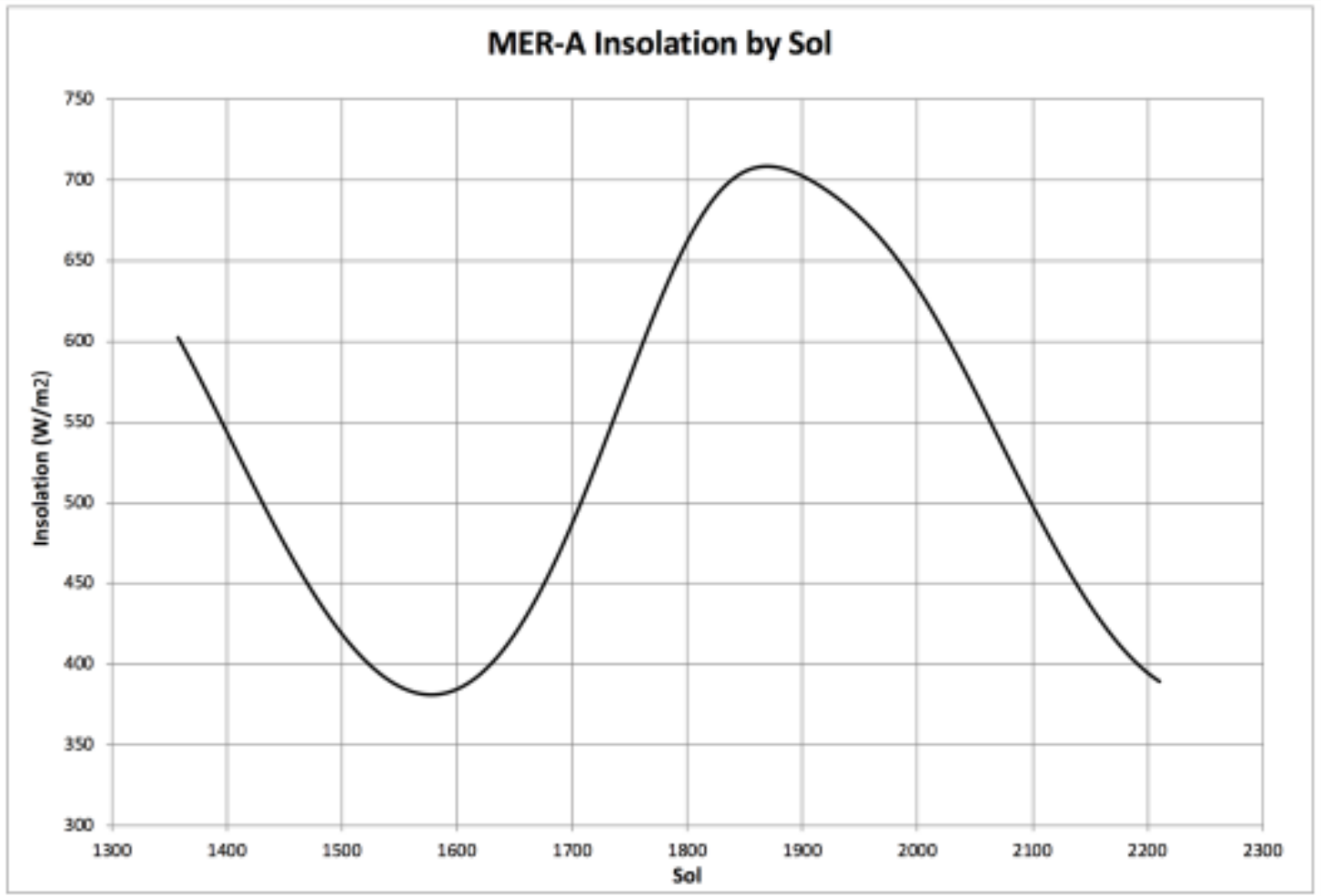
Topics

- Impact of Mars surface spectrum on PV performance
- Variation of solar insolation over the Martian year
- Preliminary development of modifications to the solar cell spectral response for the Mars surface
- Tau over the Martian year
- Dust accumulation and the role of surface winds
- Preliminary evaluation of dust mitigation methods
- MER-B performance since initial landing
- Visual impact of Tau increases
- The unexpected path to the MER solar arrays
- Summary

Mars Surface Spectrum Impact

- Spectral differences between space and Mars surface solar illumination reduces state-of-the-art space flight cell efficiencies by ~15% for Mars surface use (based on landing locations for Spirit and Opportunity)
- Overall generated cell energy is notably reduced at short wavelengths by atmospheric dust content
  - Improvement in cell performance requires increasing the multi-junction short wavelength energy contribution
- In addition, the normal incident illumination varies significantly over Martian year at a given site (see next viewgraph)
- JPL investigated cell modifications using a modified solar simulator to replicate the Mars incident surface spectrum to optimize the cell performance

Variation in Solar Insolation over Martian Year (687 Days)

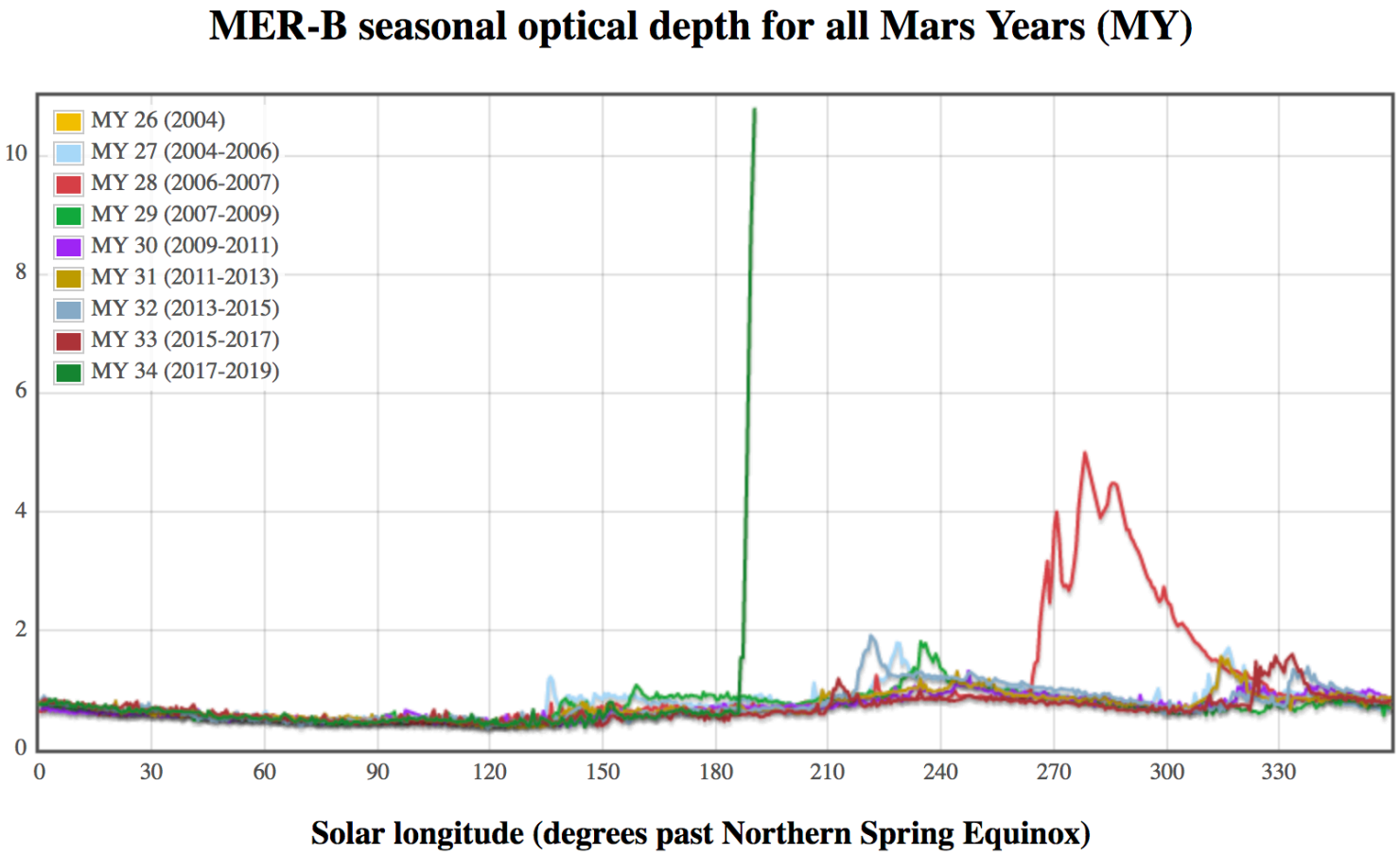


Curve shows combined effects of Solar Distance Change and Planetary Inclination – Large Change in incident normal sunlight

Cell Spectral Response Modifications

- Work initially examined a 30° off normal sun location
  - Mars tilt is 23.5° so this would include long term near equator missions (up to 6.5° North or South latitude)
  - Spirit ~15° south
  - Opportunity ~2° south
- A baseline tau (atmospheric absorption) of 0.5 was assumed
  - Reasonable condition for much of the Spirit and Opportunity missions
- Later work included a sun off point of 60°
  - Although examining the Phoenix Lander situation, it would also include long term missions at ~35°
- Work started after MER rover landings on commercial cells of that era (2004) and lead to projected Mars surface cell efficiency improvement of up to 10%
- Future work would need to extend work to contemporary multi-junction solar cells

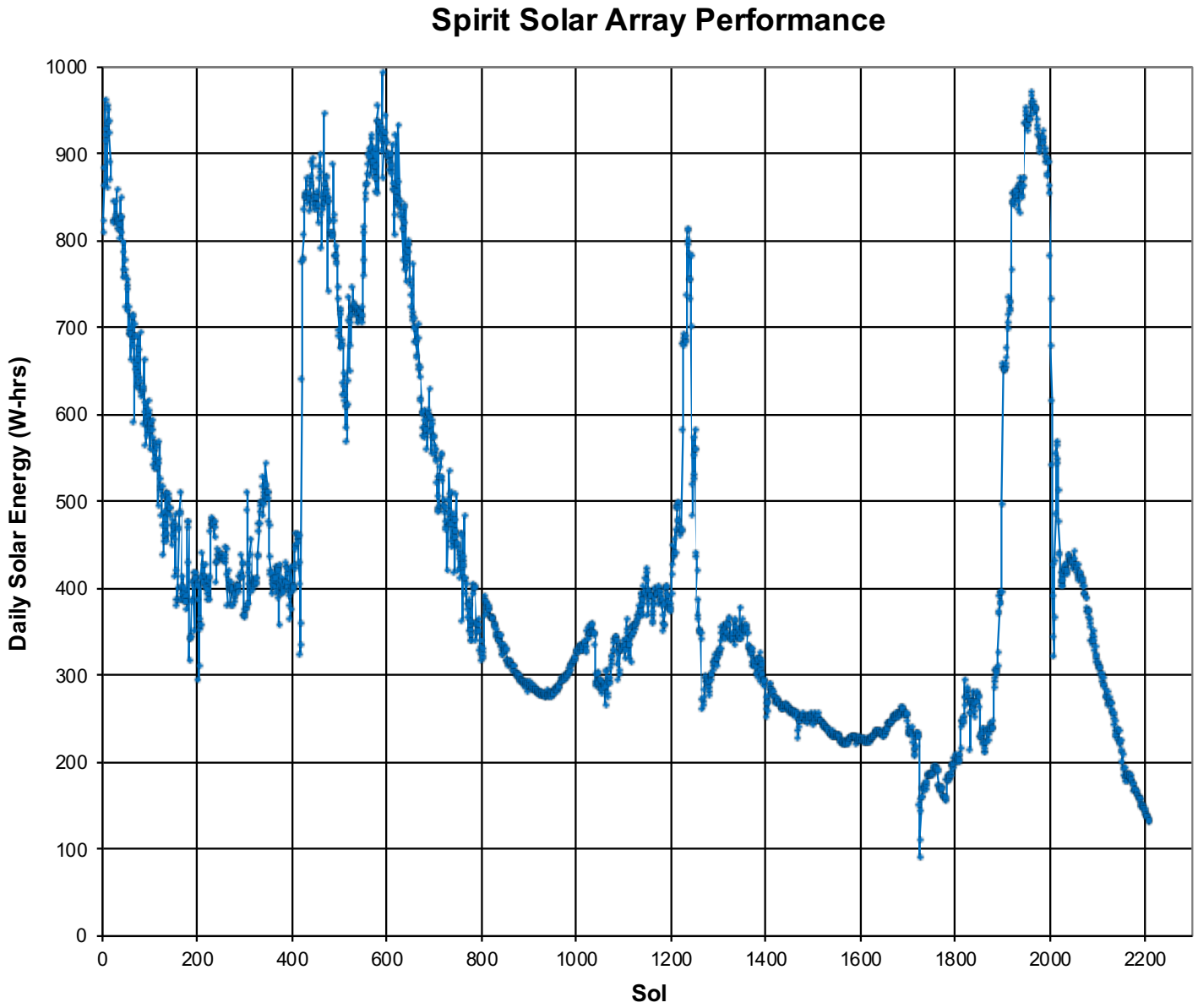
Typically, Tau has remained at ~0.5 over Most of Mission



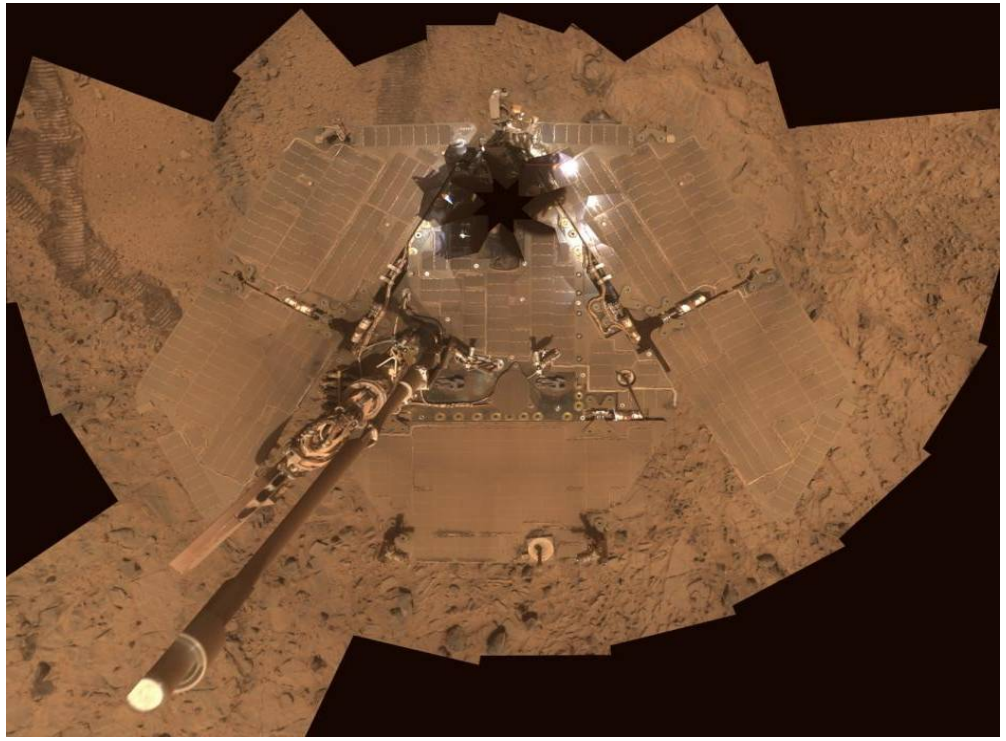
Ref. Dr. Mark Lemmon of the Mars Exploration Rover science team and the Space Science Institute, 2018

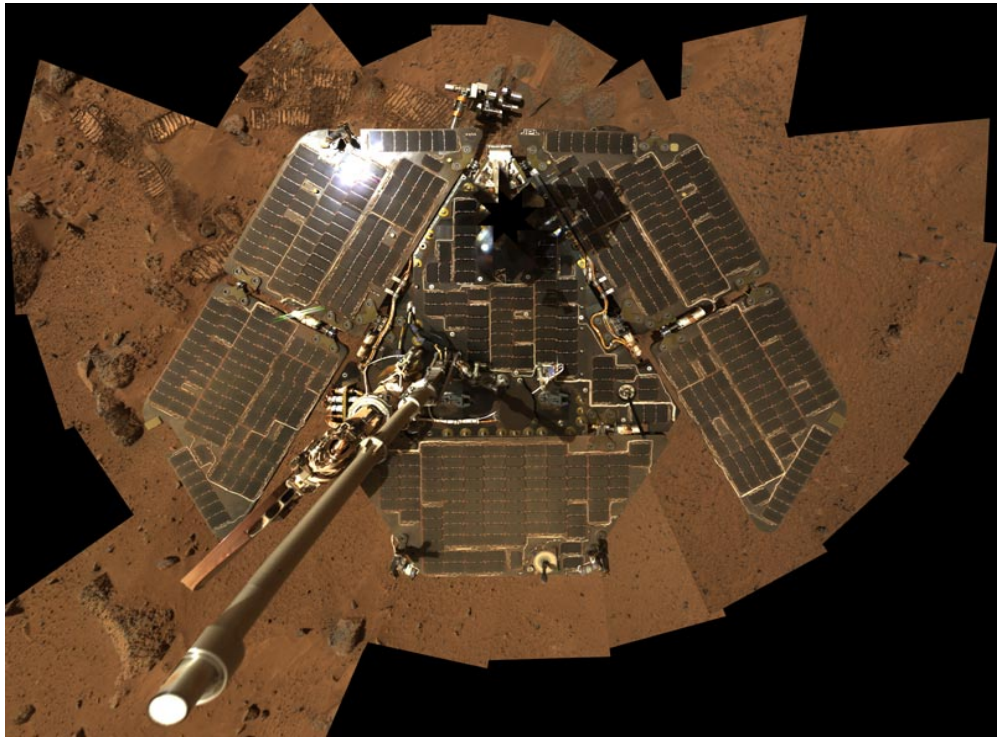
Dust Accumulation Repeatedly Reduced by Martian Winds

Winds incur major removal of dust from panels, increasing solar array energy



Removal of Dust on Rover Solar panels by Martian Surface Winds

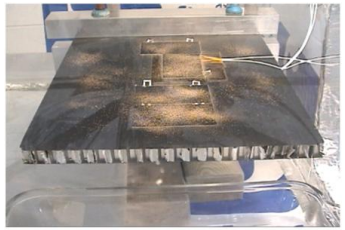


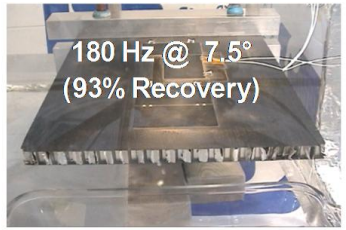


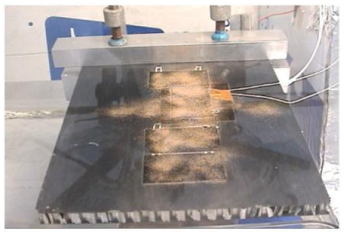
This has occurred to different cleanliness levels repeatedly over the mission lifetime

Dust Mitigation Methods Assessed After MER landings

- Electrostatic Repulsion
  - Required additional structure over cell panel
- Dust Shake-off
  - This required vibrational tools on panel back-side
  - Ground tests show high level of dust removal from short duration vibrations



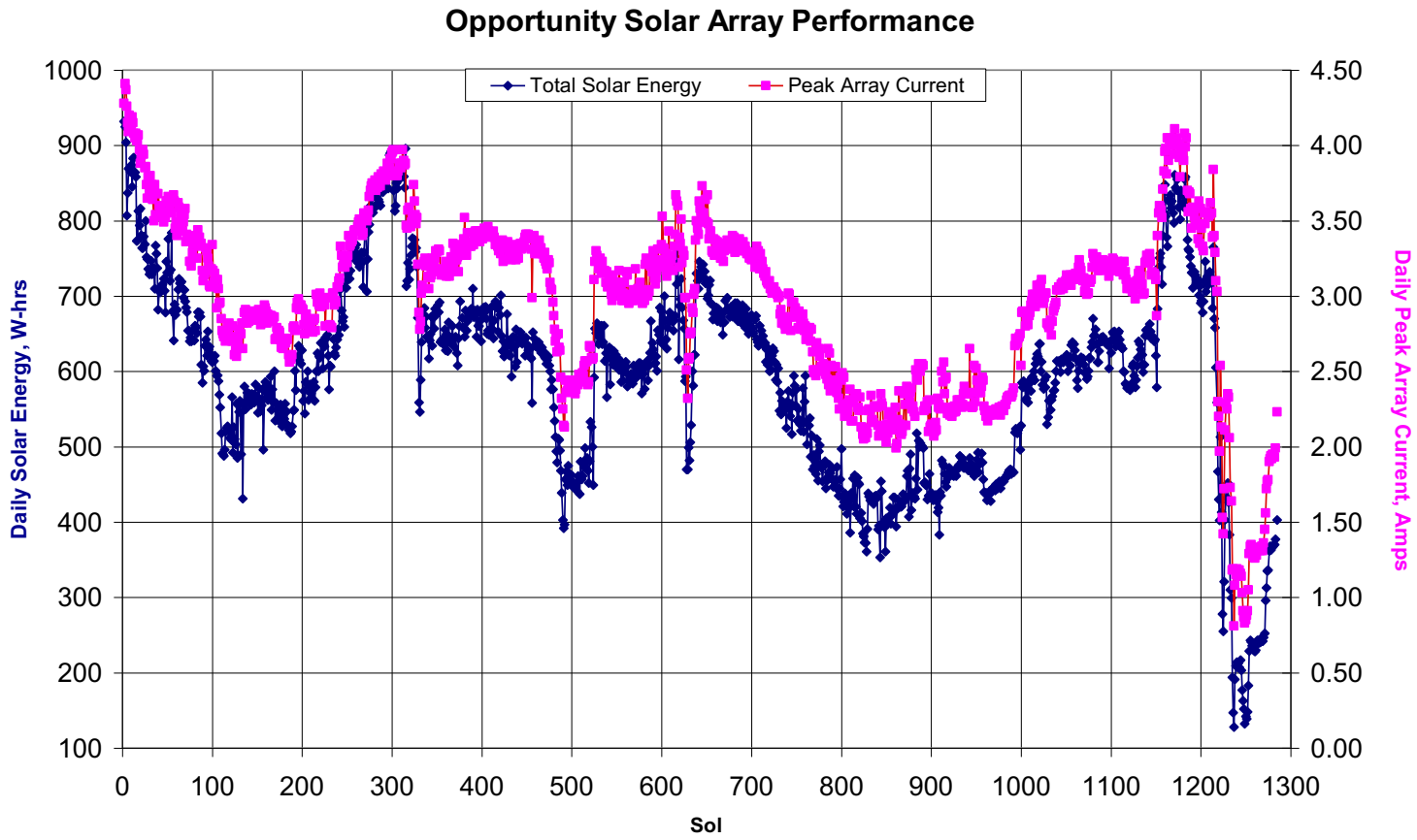




Recovery is defined as amount of full transparency following vibrational dust removal operation

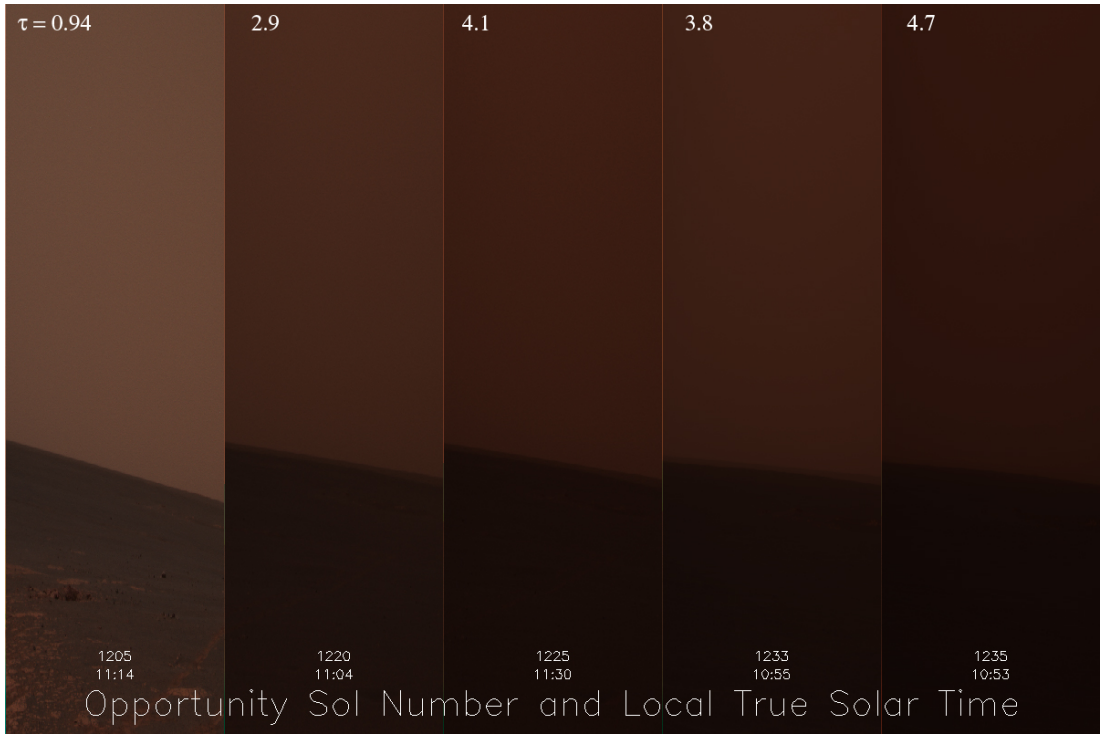
MER-B Performance After Landing

As with MER-A, (Spirit), atmospheric wind removal of deposited panel dust is seen similarly for MER-B, (Opportunity)



- Impact of Planetary Wide Dust Storm at ~ Sol 1220 – 1280
- **Both Rovers Exceed Viking Surface Operation Duration by End of August, 2007**

Visual Impact of Atmospheric Tau Increase



As can be seen, the Mars dust storms can significantly reduce the available sunlight for the panel. Typically, a tau of ~0.5-0.7 is common during much of the Martian year. Recent major Martian dust storm had an indicated tau of > 10!

The Unexpected Path to Making the MER Rover Arrays

- Initial award for the MER solar panels was awarded June 2001
  - Contract delivery date was June, 2002
- Contractor announces bankruptcy in Jan, 2002
  - Solar panel substrates are at vendor and have had initial preparation
- Feb, 2002, JPL notified of potential buyer of cell and panel business
  - Vendor would need to develop qualified panel manufacturing processes
  - JPL also looking at other potential vendors
- Spectrolab selected by JPL to continue manufacturing
  - Solar panel substrates delivered to Spectrolab by JPL after receipt from initial contractor's facilities
  - Change in design for cell type and size implemented to use standard Spectrolab cell
- Accelerated manufacturing cycle by Spectrolab allowed launch to proceed on schedule in June and July 2003!

Rover and Stationary PV Improvements for Mars

- Previous (Old) studies strongly suggest that surface PV power on Mars can be notably enhanced
  - No new PV missions to the Mars Surface Since Phoenix (2008)
  - Missions use standard AM0 cell technology and no dust removal methods
- The most dramatic results should follow from dust removal methods
  - Dust factor has varied from ~0.9 to ~0.2 for MER
  - In 2018, the dust factor reached close to initial mission values (>0.85)
- Additional performance increase would come from tailoring the cell design to the short wavelength Mars surface solar spectrum
- Combination of these cell and panel changes projected to allow doubling of PV generated power over mission lifetime (15 years for Opportunity to date)
- Robust dust storm survival methods need research and development