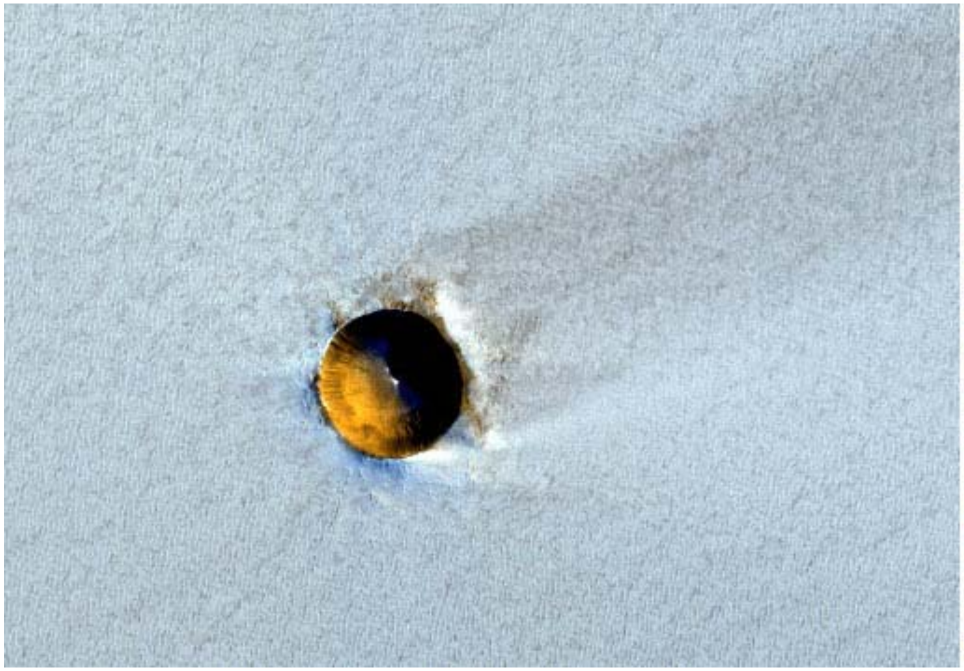
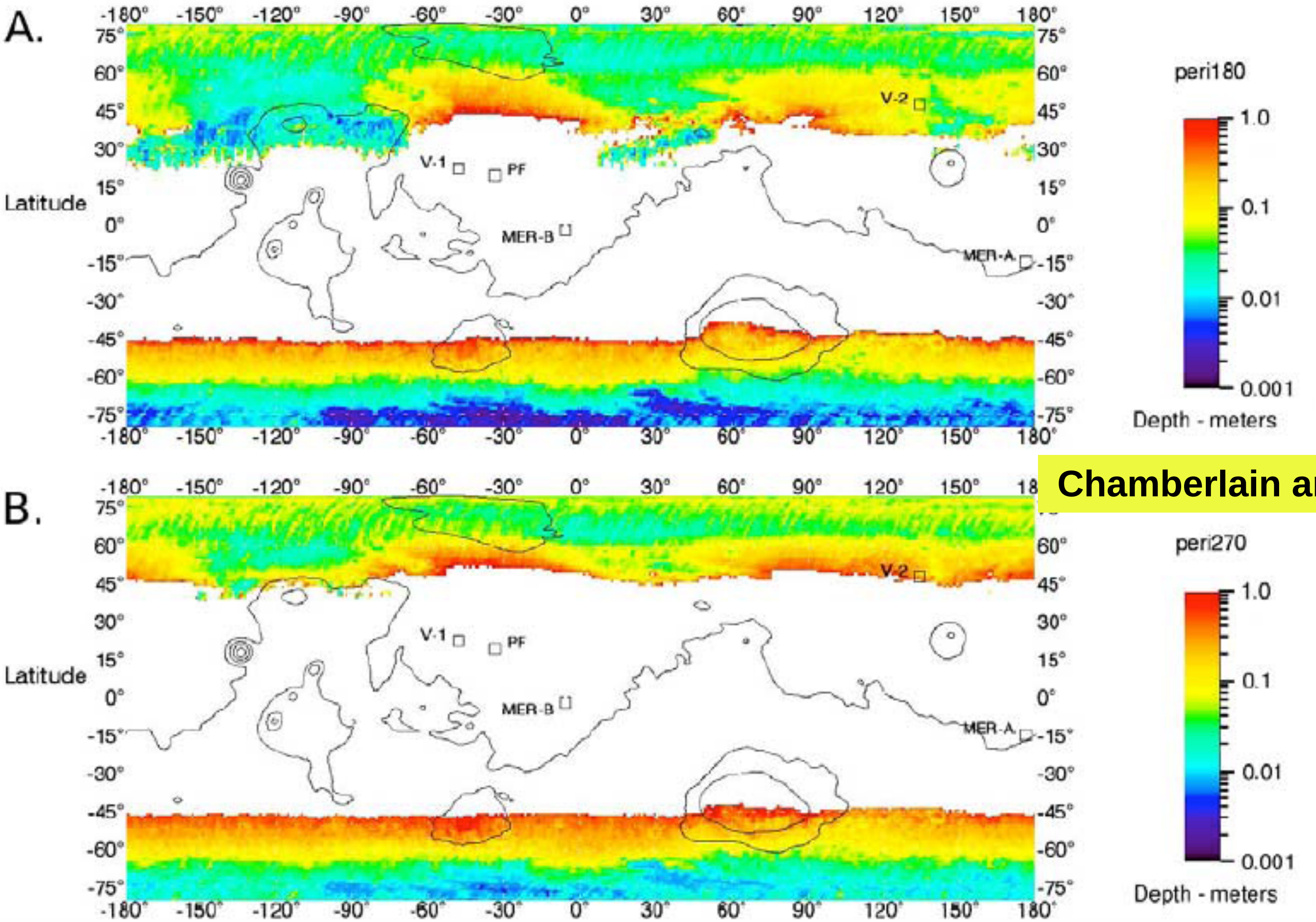
North Polar Ice Accumulation Modeled from Impact Crater Statistics

S. Byrne, M.E. Banks, C.M. Dundas, S. Mattson, P.S. Russell, K.E. Herkenhoff, A.S. McEwen and the HiRISE team.



- Mid-latitude ice becomes unstable over the recent past
- Drives polar cap accumulation

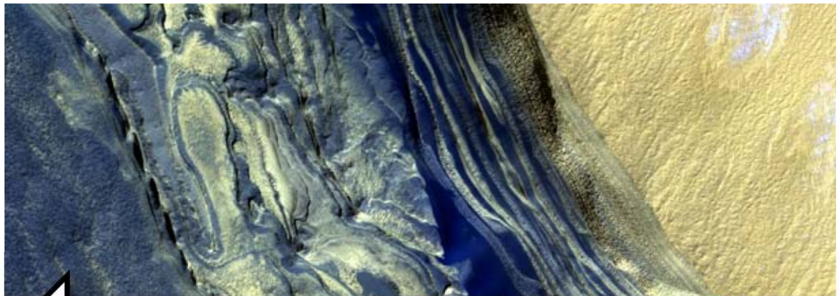


10 Kyr in the past

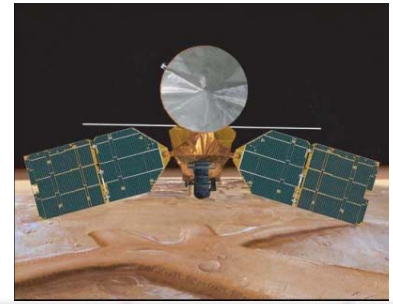
Chamberlain and Boynton, 2007

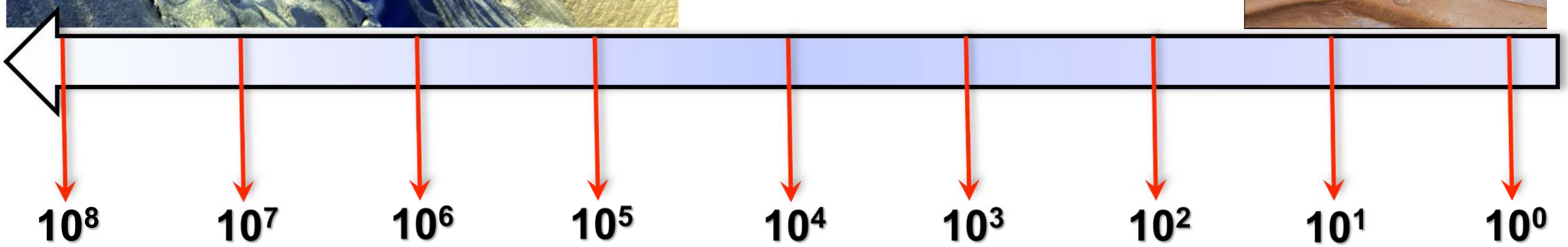
3 Kyr in the future

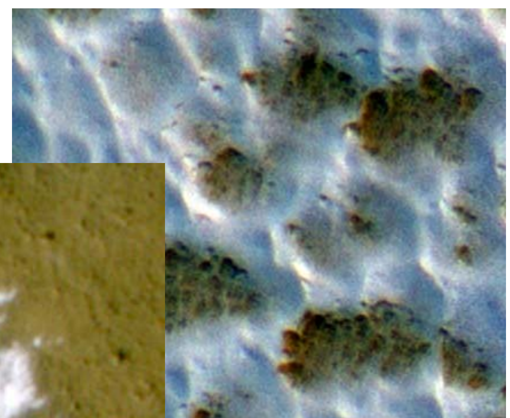
Polar Accumulation Modeled from Impact Craters



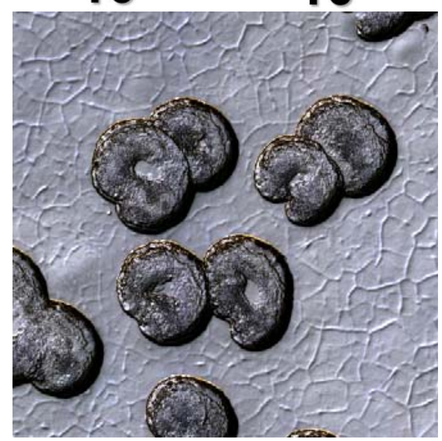
Residual caps fill this gap





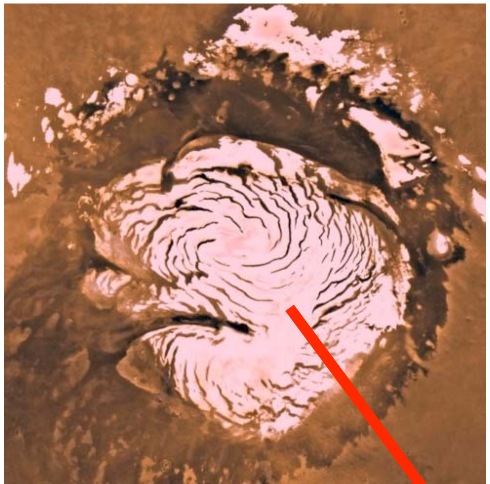


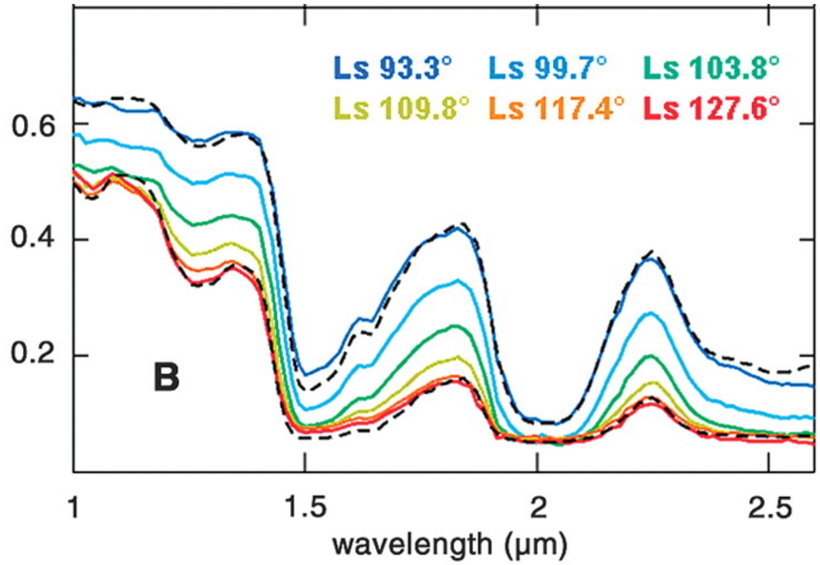
Recent climatic variations



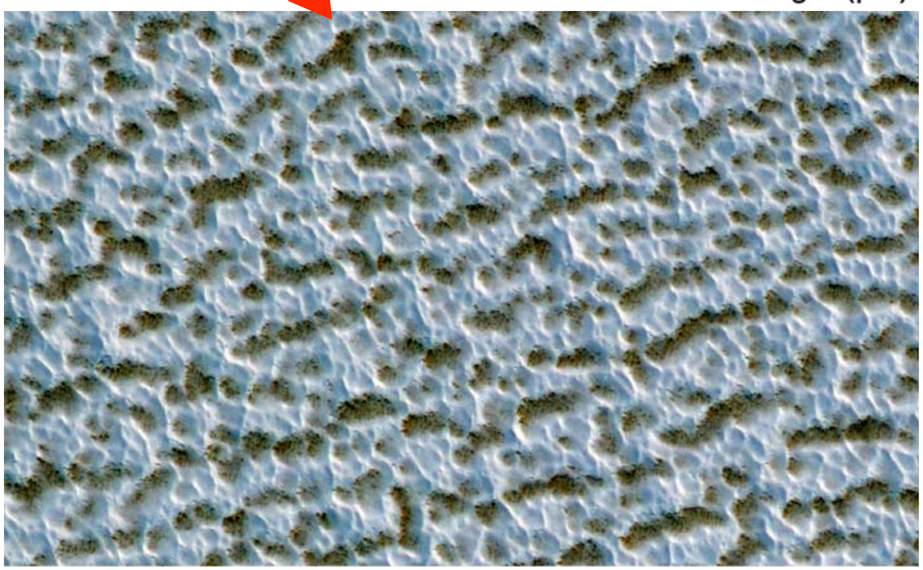
Interannual variability of the current climate

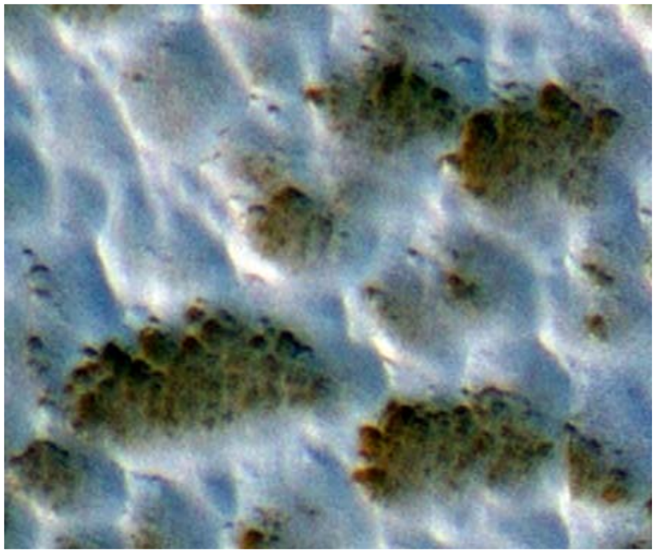
- **Two problems with this…**
  - **1. The residual cap is suffering net ablation at the moment.**
    - **OMEGA spectra indicate old ice is exposed each year**



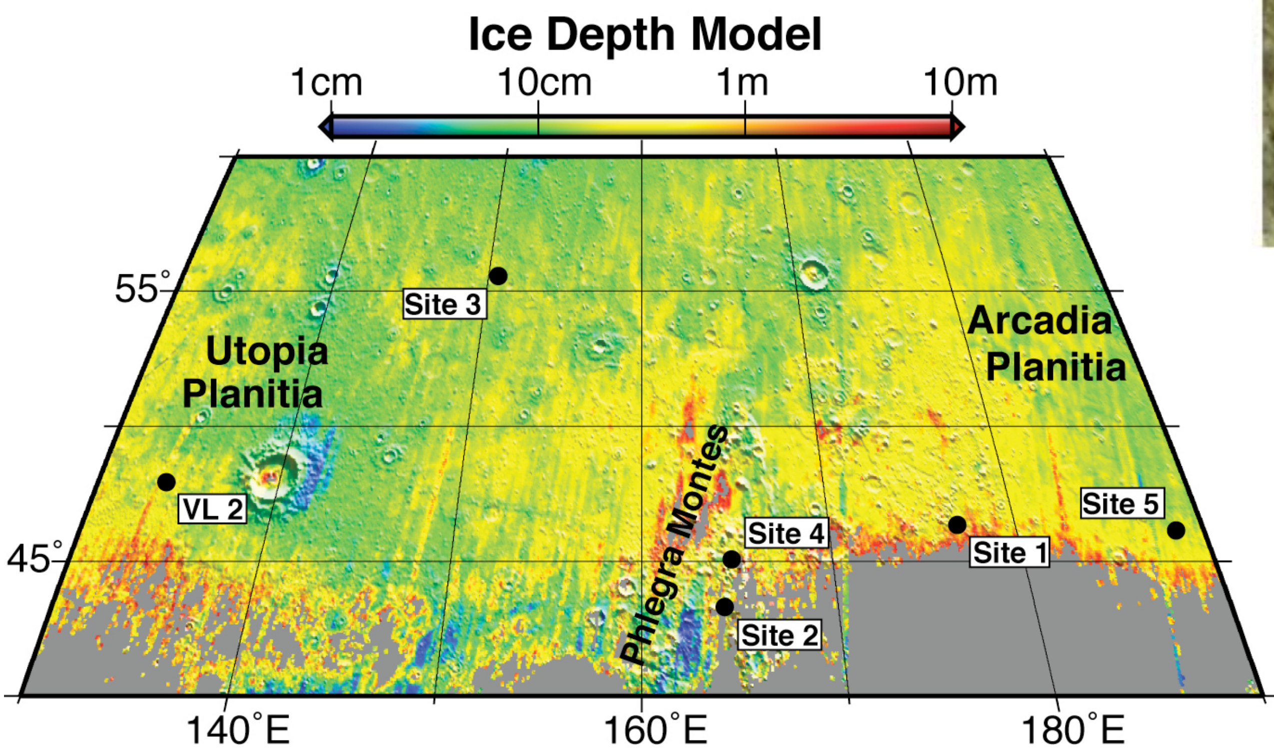


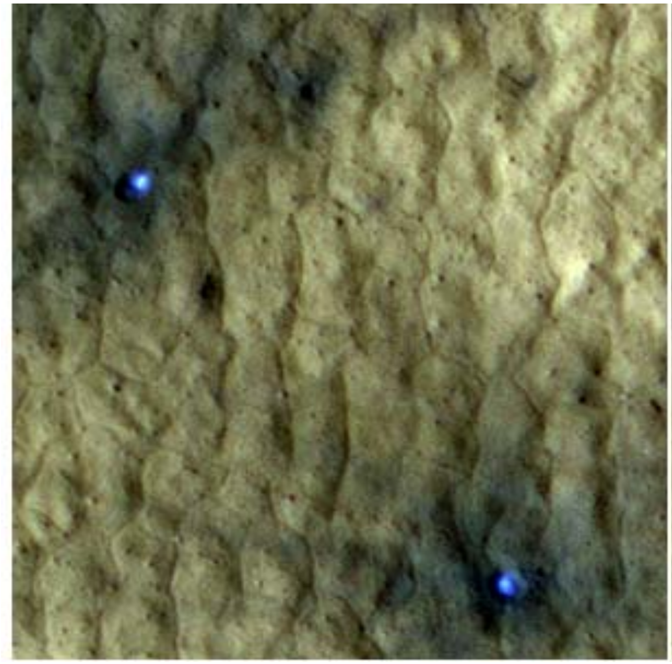
Langevin et al., 2005





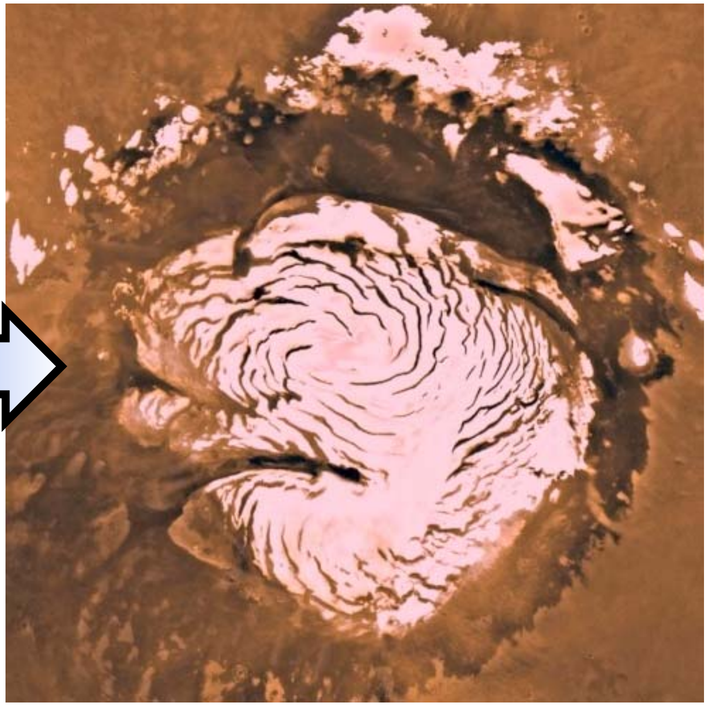
- Two problems with this…
  - 1. The residual cap is suffering net ablation at the moment.
  - 2. The mid-latitude ice isn't retreating as fast as it should.
    - Ice is a relic of a more humid atmosphere



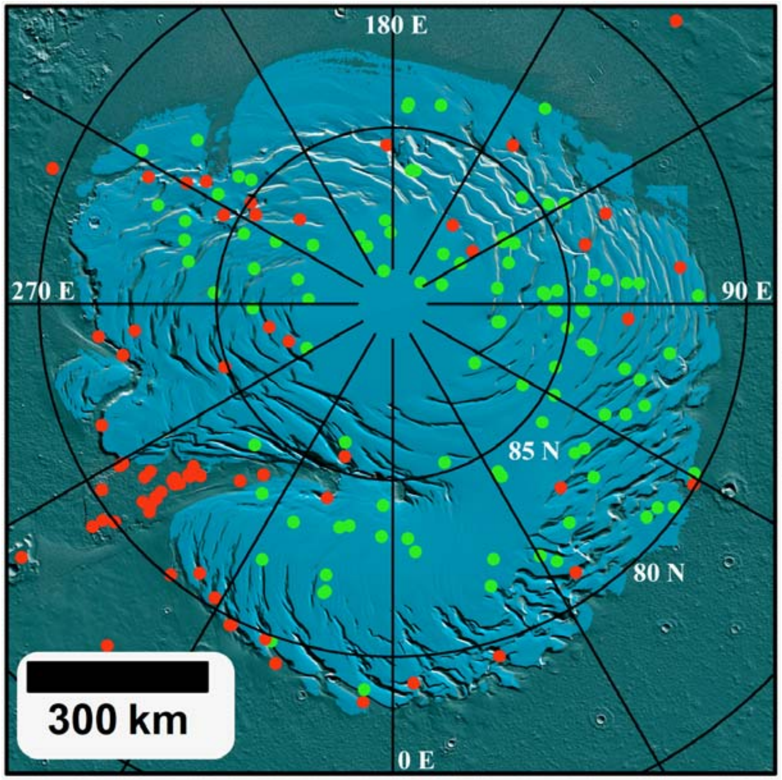


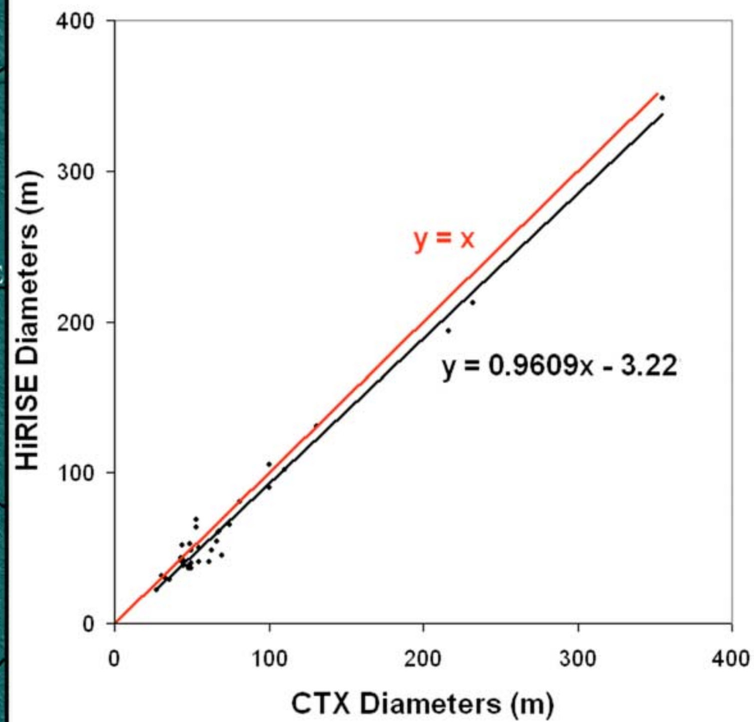
- **We know what the ice *ought* to be doing but have is it *actually* doing?**

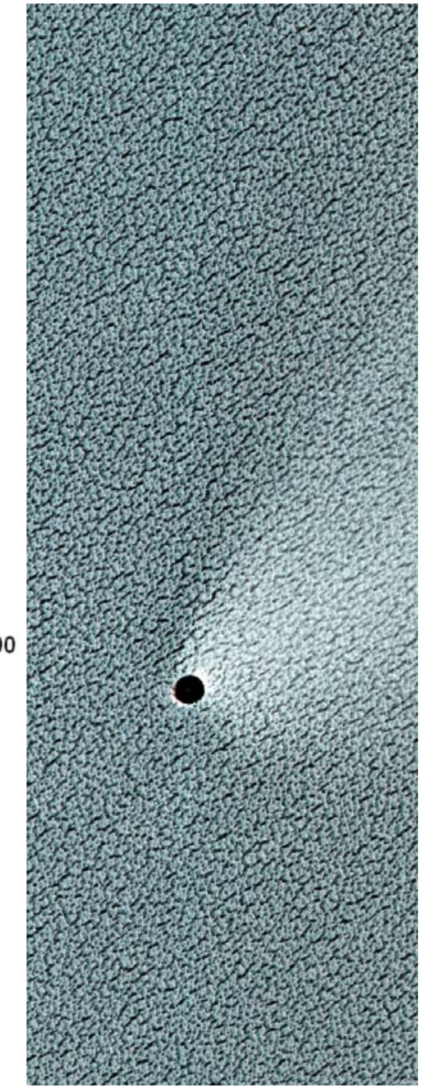
?



Polar Accumulation Modeled from Impact Craters



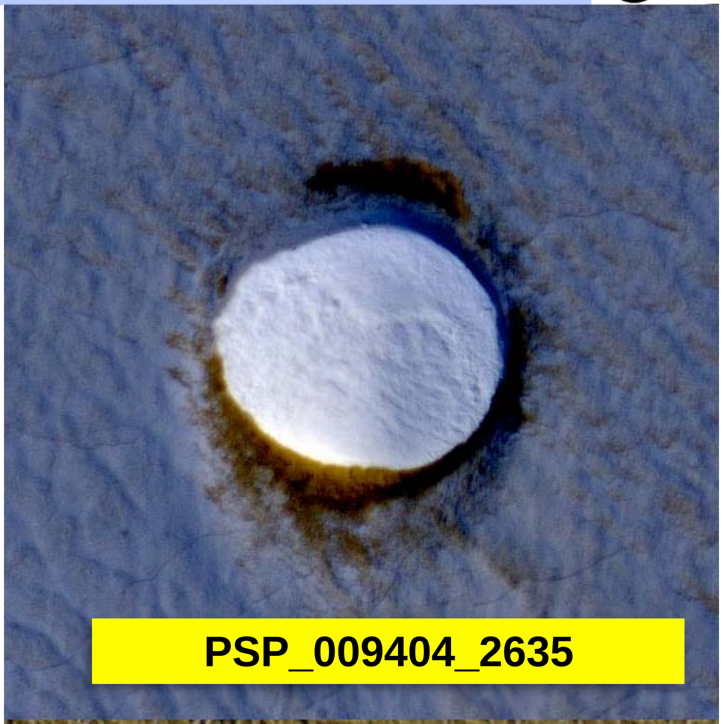




- **CTX search**
  - **103 craters in ROI (green dots)**
- **HiRISE follow-up**
  - **Accurate sizes – focus on smaller craters**
  - **Morphologic sequence of degradation – focus on larger craters**
  - **43 craters in ROI (calibrates CTX diameter measurements)**

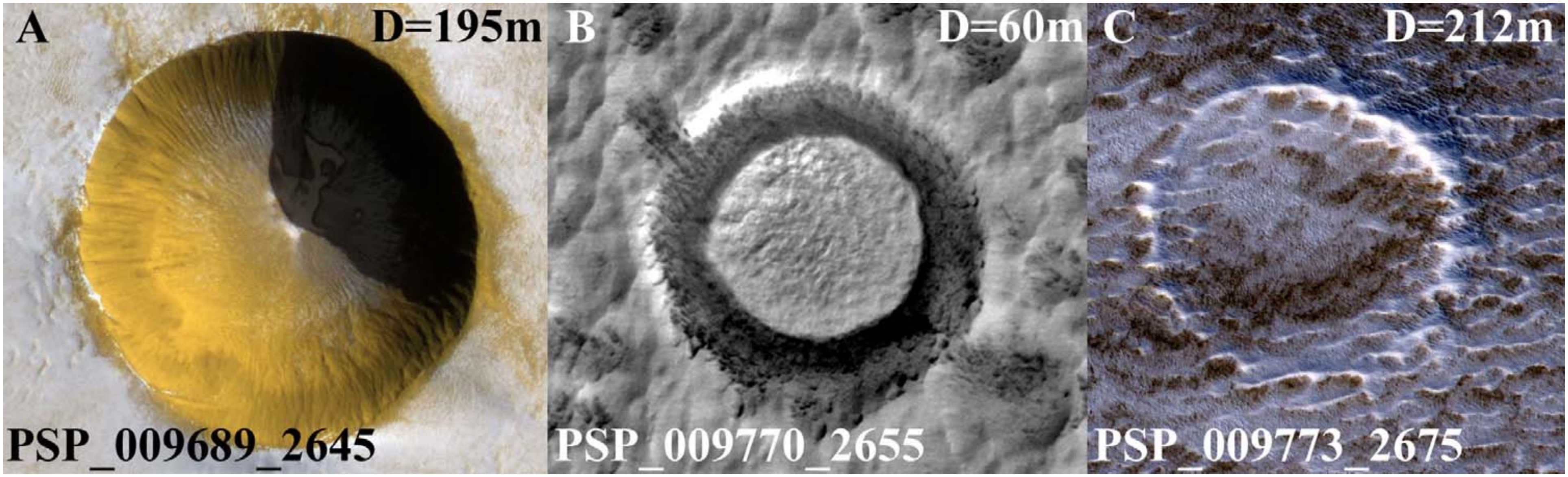
Polar Accumulation Modeled from Impact Craters

- Interior of craters a site of net ice accumulation
  - Compared to the darker (larger grained) old ice in the residual cap



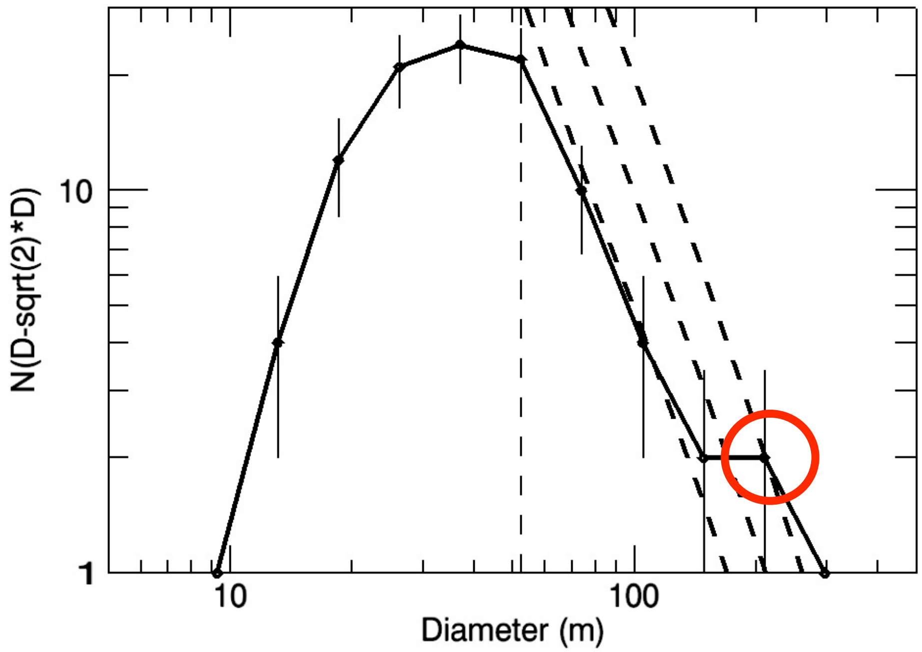
- Morphologic sequence
  - Craters fill with ice
  - Ablation features (sun cups) chop up the rims

  - Some craters virtually ice free
  - Freshest craters have d/D up to 0.22

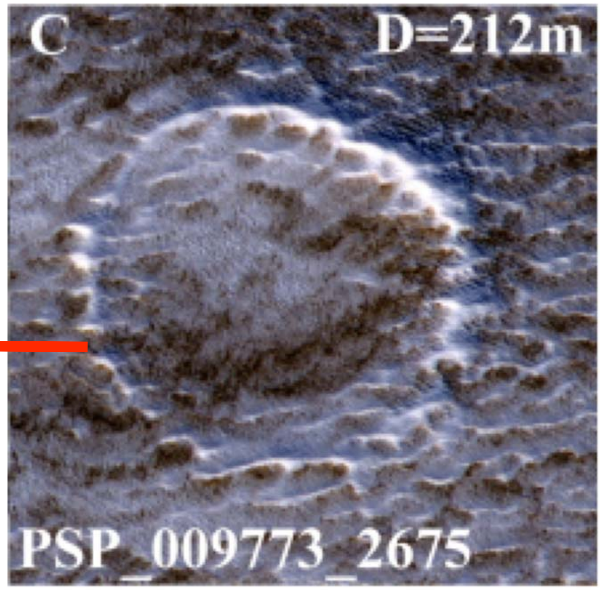


Polar Accumulation Modeled from Impact Craters

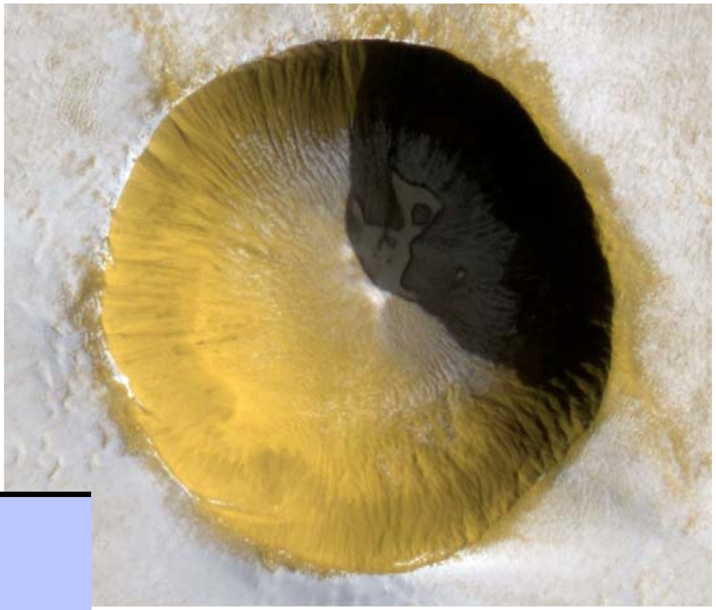
- Bins with only one crater not considered
- *production x lifetime = population*
  - production & population known
  - Can find the crater lifetime…
- Numbers depend on the last bin…



	Largest bin included	Largest bin excluded
Crater lifetime	30.75 $D^{1.14}$ yrs	302 $D^{0.61}$ yrs
Remove 212m crater	13.8 Kyr	7.8 Kyr
Remove 350m crater	24.6 Kyr	10.6 Kyr



Polar Accumulation Modeled from Impact Craters

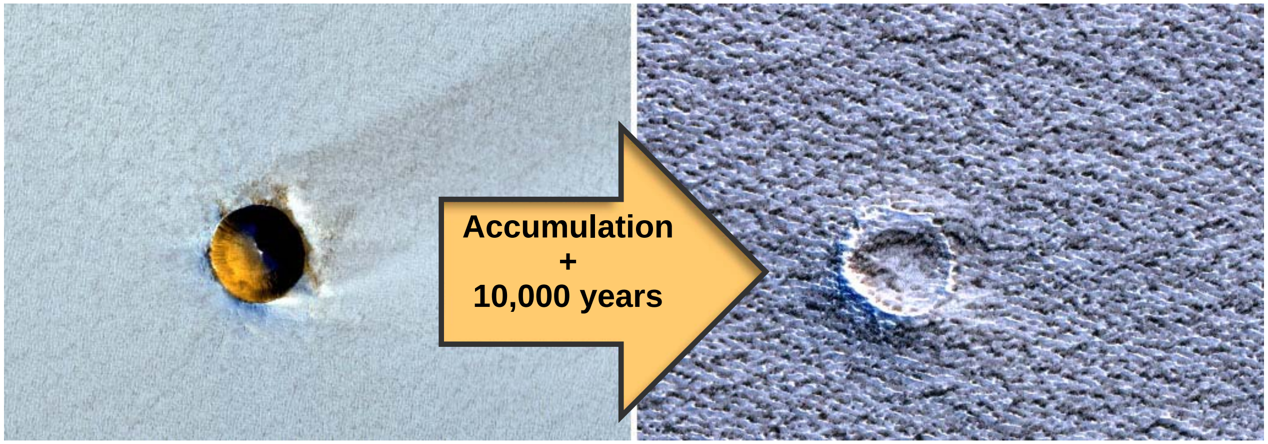


- **Accumulation rates?**
  - **We know how long it takes to remove a crater**
  - **Assume removal is due to accumulation**
  - **Accumulation rate = depth / crater lifetime**
- **What's the original depth?**
  - **Depth = 0.22 * D**

	Largest bin included	Largest bin excluded
Crater lifetime	30.75 $D^{1.14}$ yrs	302 $D^{0.61}$ yrs
Accumulation rate	7.2 $D^{-0.14}$ mm/yr	0.72 $D^{0.39}$ mm/yr
Accumulation rate	3.4 - 4.2 mm/yr	4.2 - 7.6 mm/yr

- **Rates are an order of magnitude faster than might occur on the NPLD**
  - **Mechanical properties of ice mean craters might be artificially large i.e. rates might be even higher…**

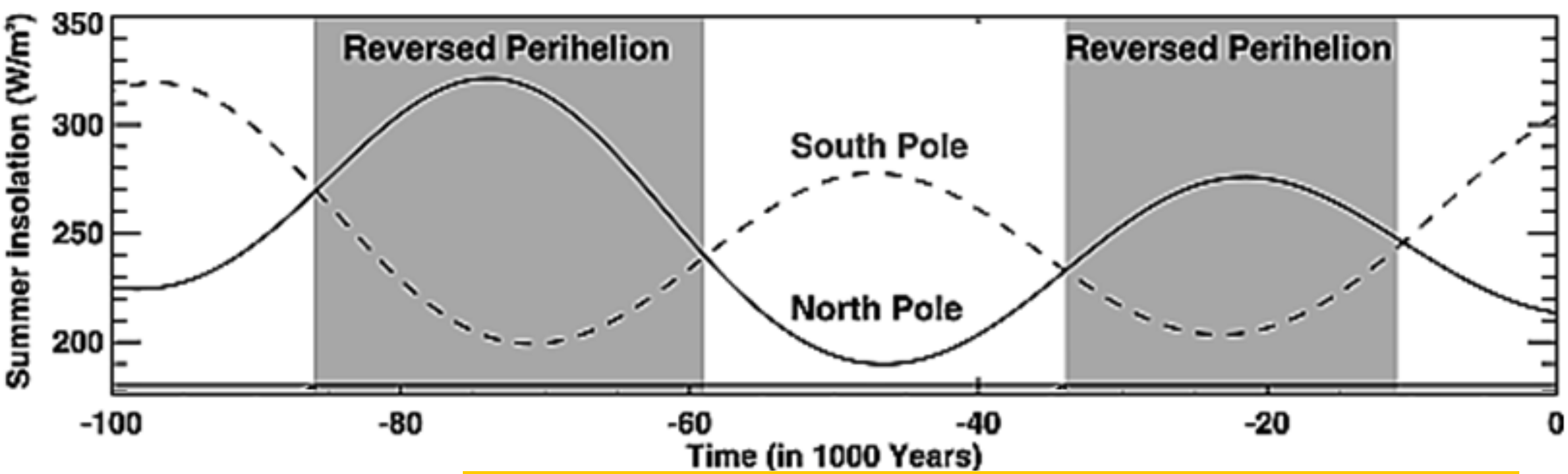
Polar Accumulation Modeled from Impact Craters



- **Significant amounts of ice were transported to the polar cap over the past 10 Kyr**

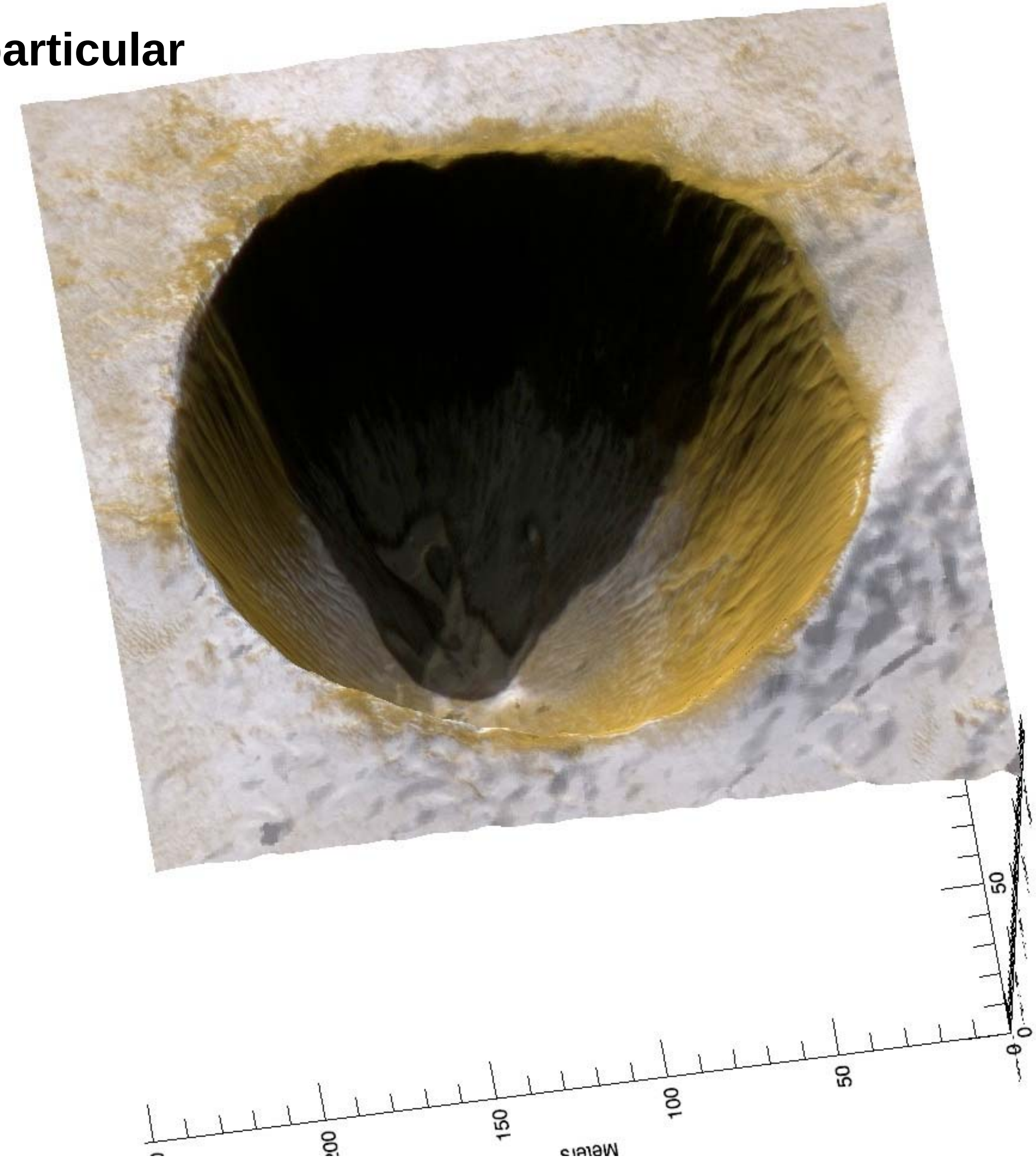
	Largest bin included	Largest bin excluded
Population time	13.8 – 24.6 Kyr	7.8 – 10.6 Kyr
Infill rates	4-5 mm/yr	5-9 mm/yr

- **Next step is to relate crater infill rates to landscape polar cap accumulation rates**



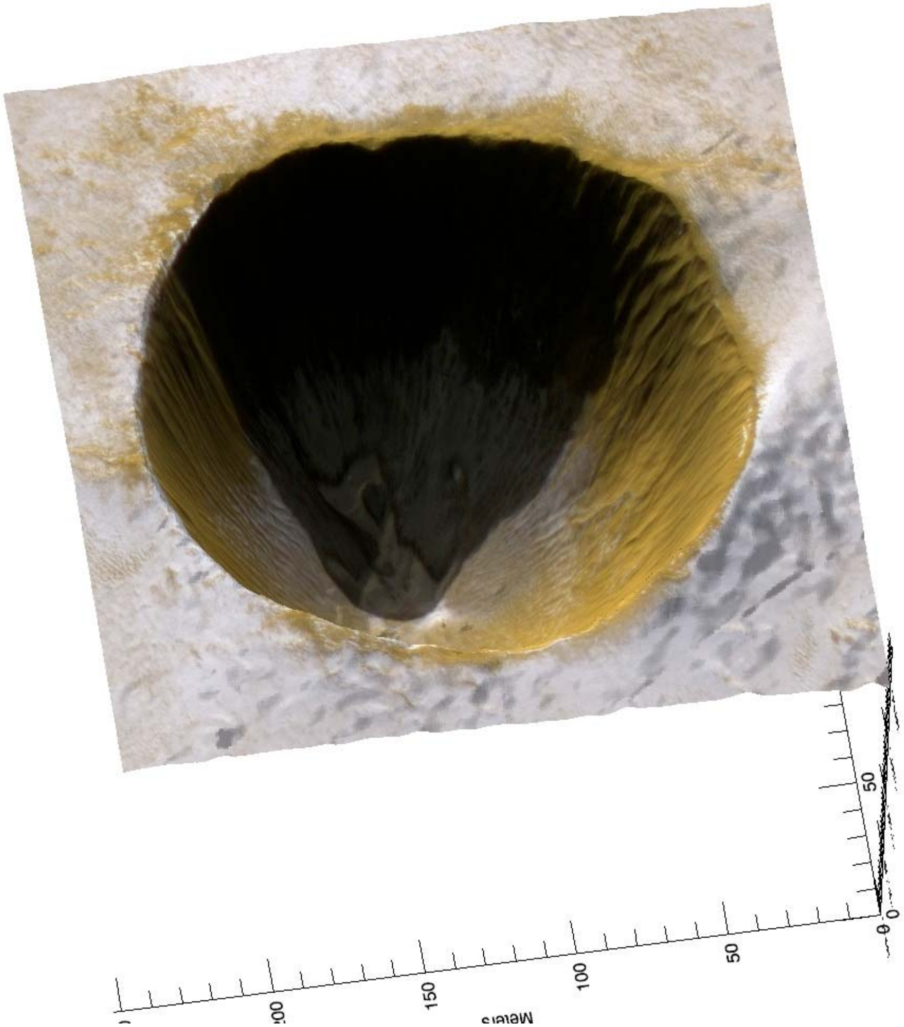
Montmessin et al., JGR, 2007

- Investigate one crater in particular
- Stereo DEM available
  - 1m posting
  - Accurate to ~1m

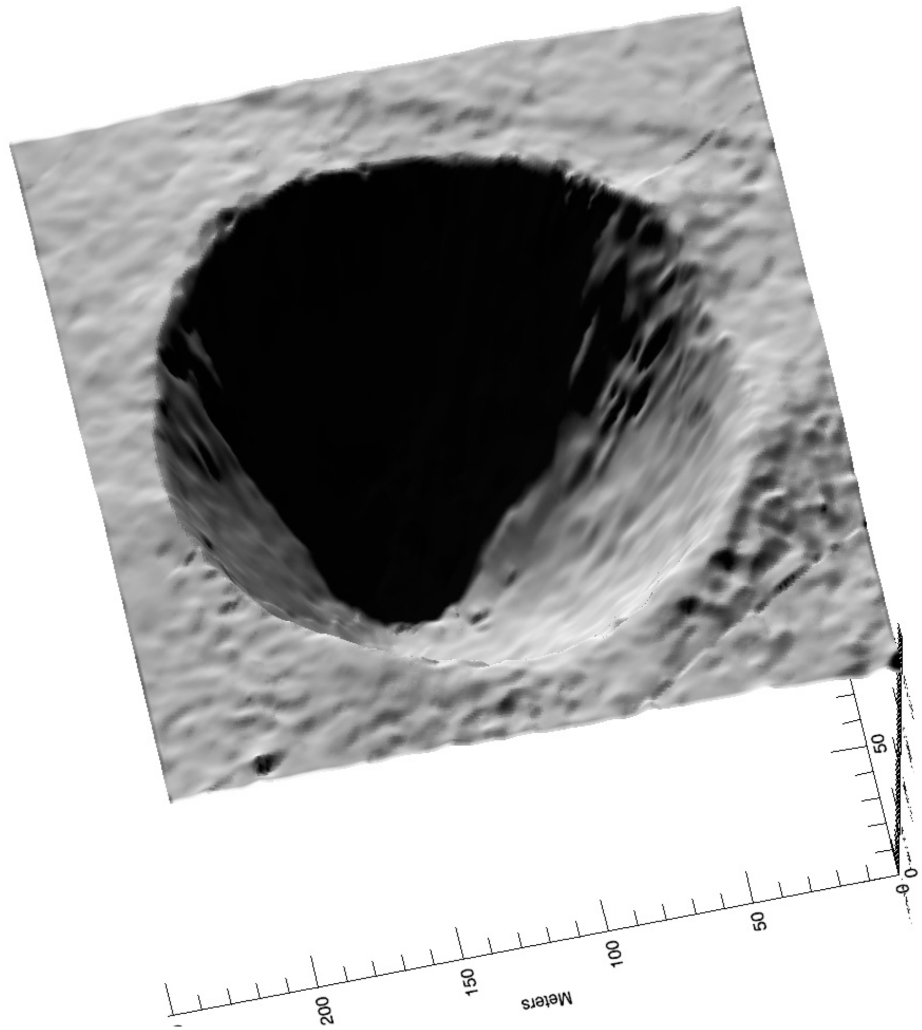


Polar Accumulation Modeled from Impact Craters

- **Quality of the DEM is very high**
  - **Shadow shapes match**

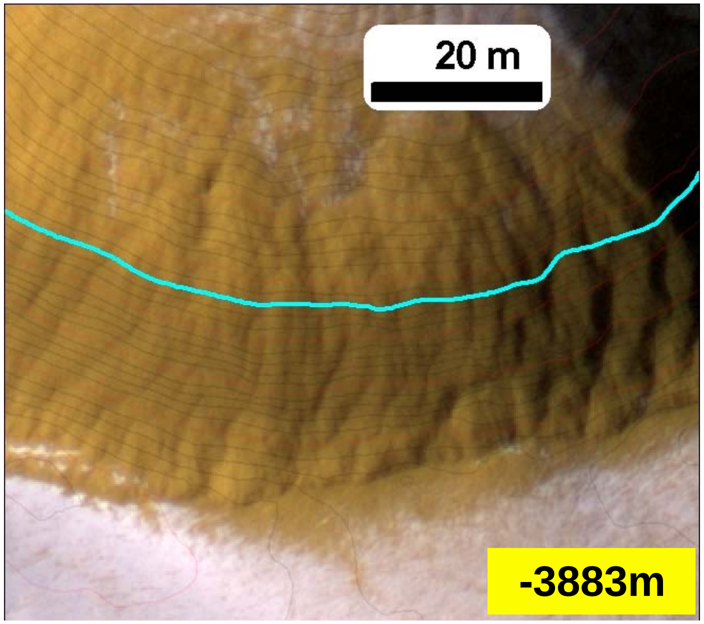


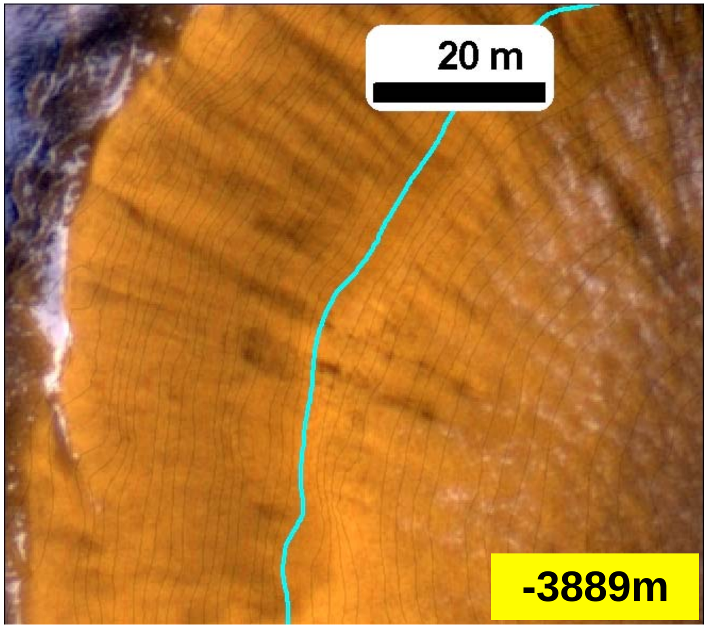
Original imagery

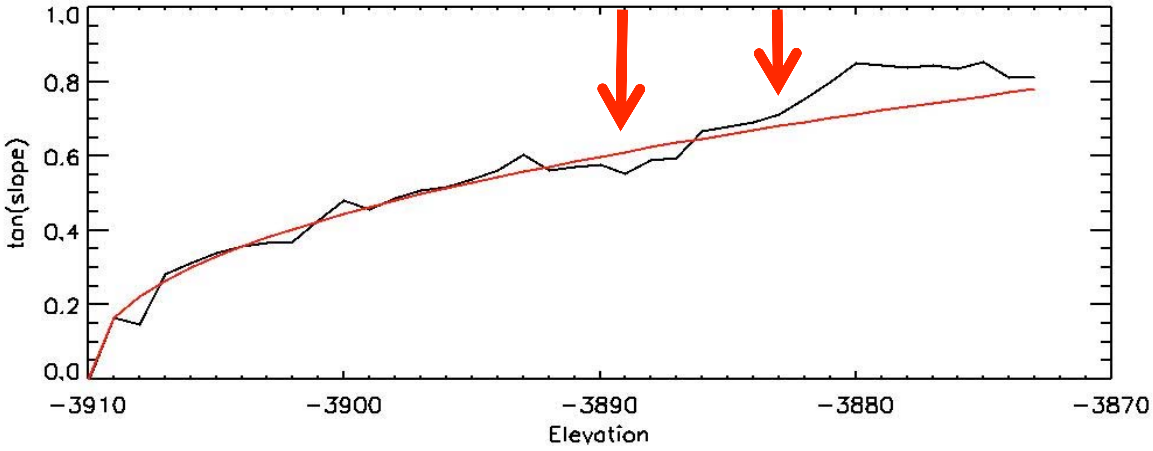


Shaded relief

Polar Accumulation Modeled from Impact Craters



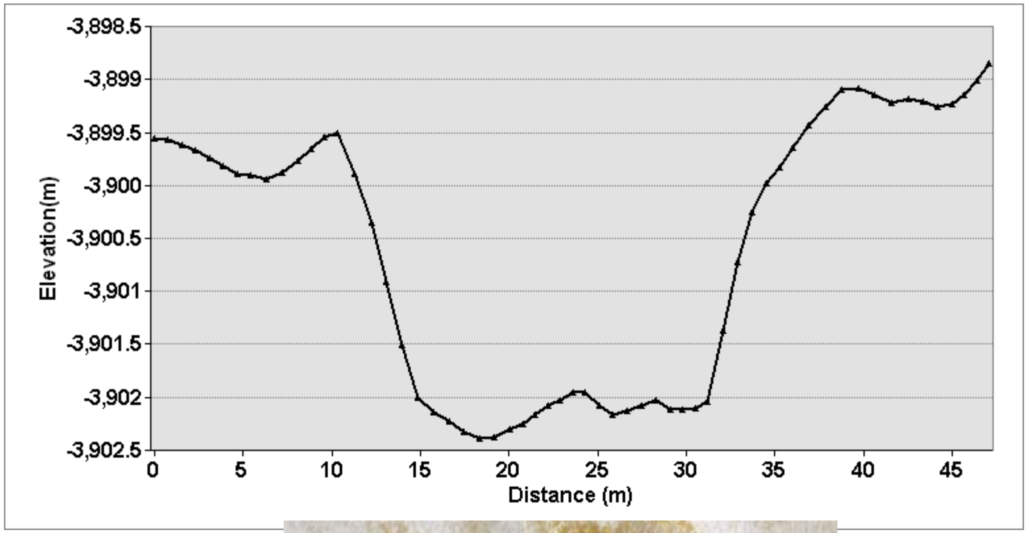


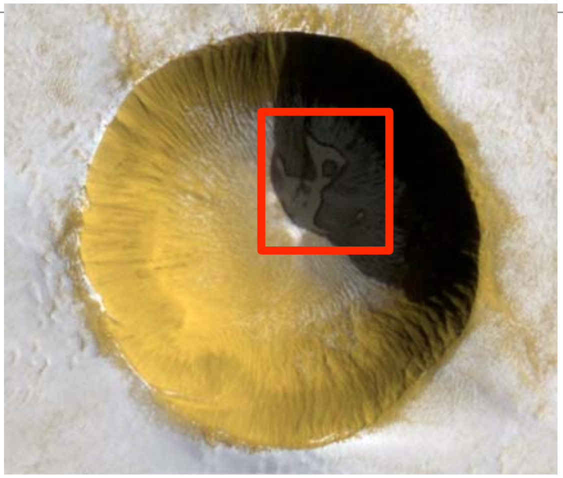


- Crater shape changes coincide with albedo changes
  - Change in the material 25±3 m deep?

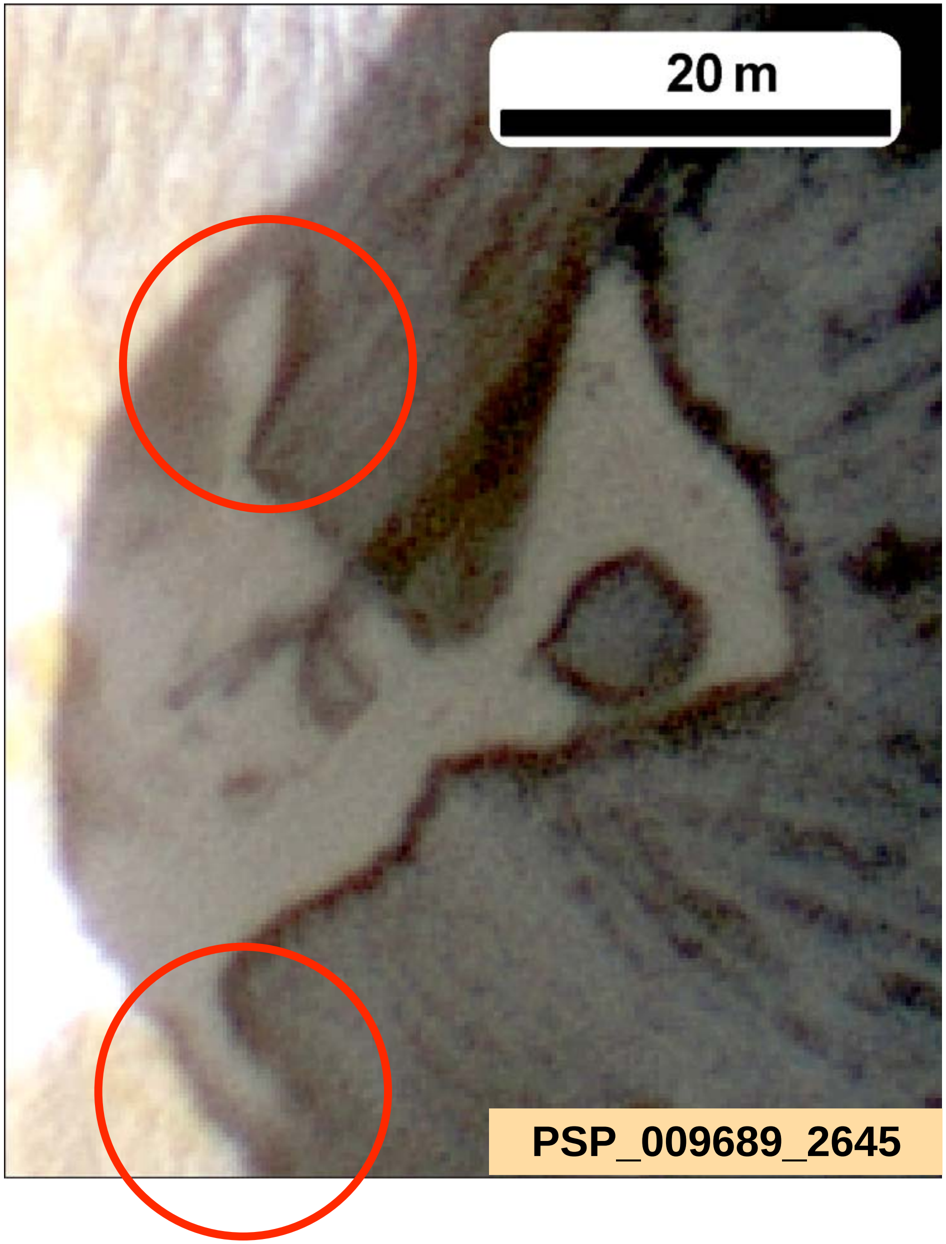
- Stereo topography shows ice patch is a low (opposite of what I thought)
  - Original crater floor not covered up yet

Lots of work by Sarah Mattson

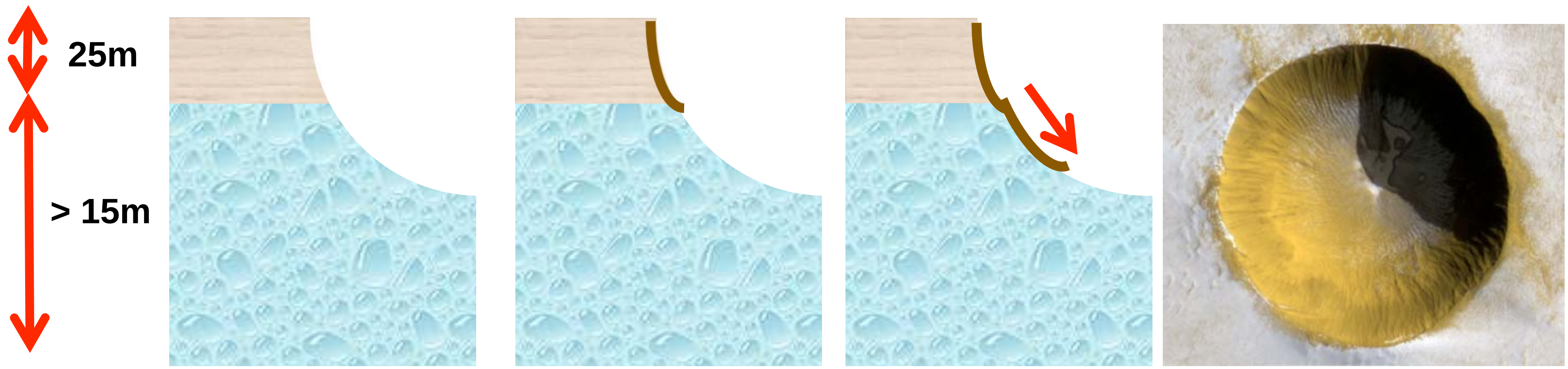




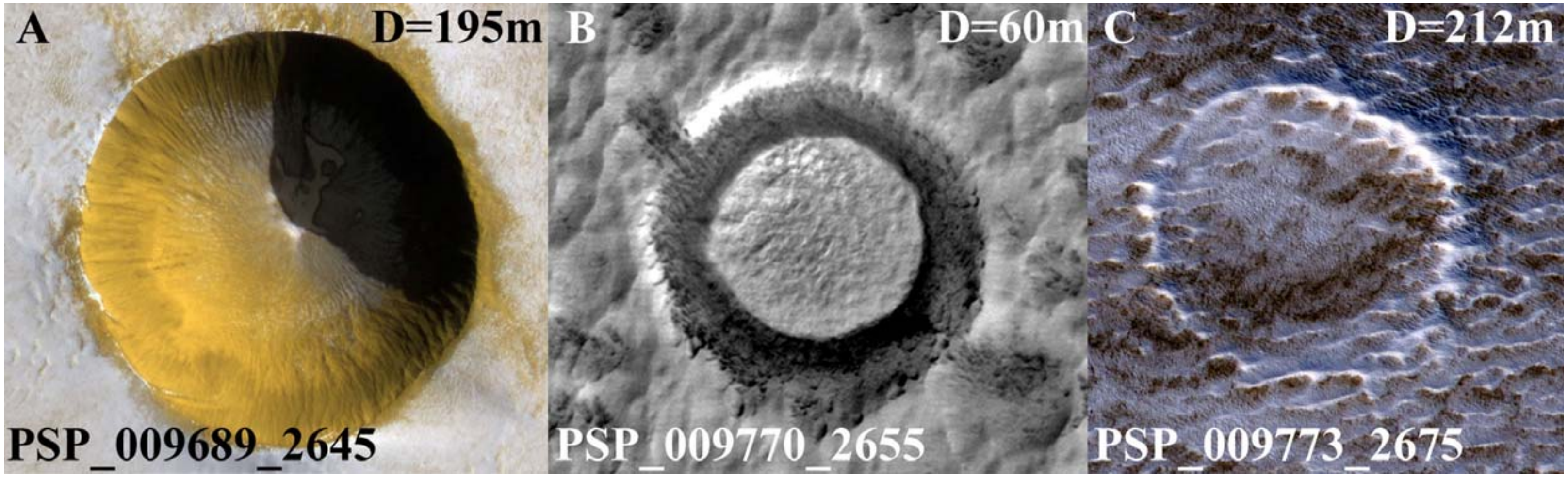
- Changes in 400 orbits?
  - Orthorectified versions look similar, but lower resolution



- Conceptual model
  - A dirty ice layer over cleaner stuff
  - Ablation and slumping of lag cover interior



- Shadowing and low-inertia lag promotes frost retention
  - Ice accumulates within cavity

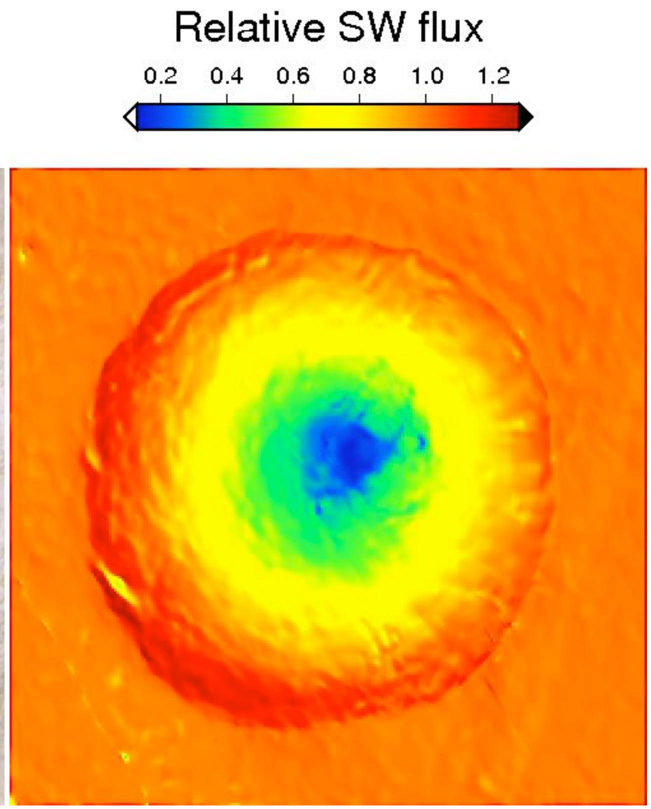


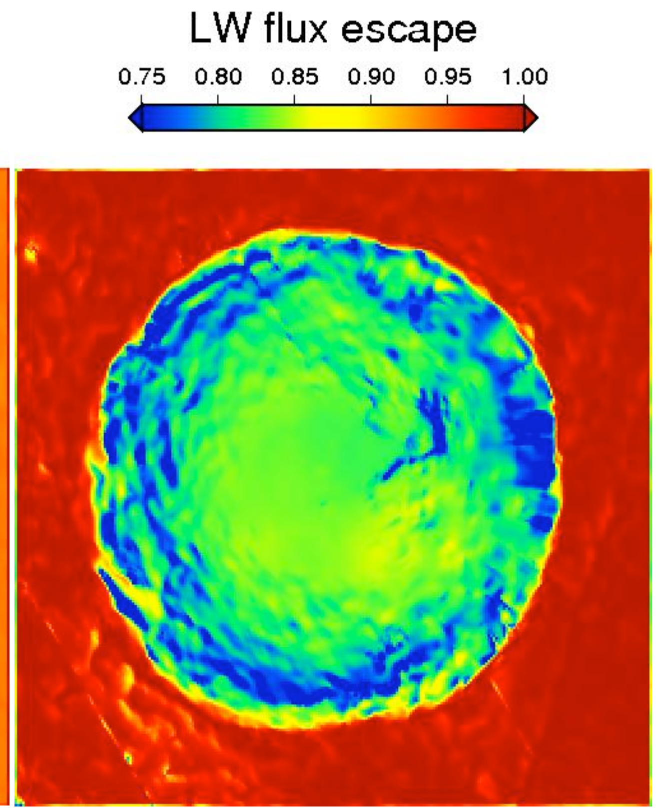
Polar Accumulation Modeled from Impact Craters

- **How fast?**
  - **>32 years for phase 1**
  - **Several Kyr for phase 2**

Polar Accumulation Modeled from Impact Craters

- **Slope/aspect effects**
- **Shadowing**
  - **Pronounced effect**
- **Sky view reduction**
  - **Not that significant**





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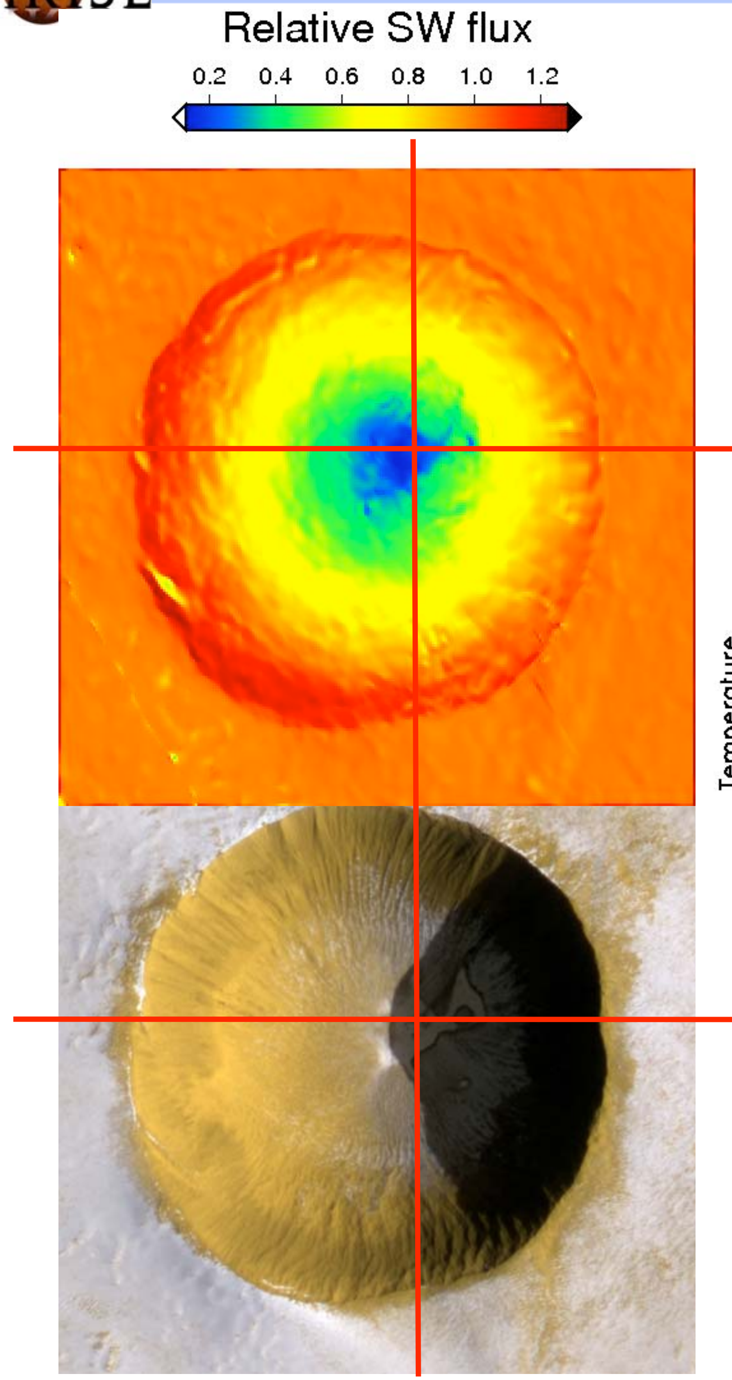
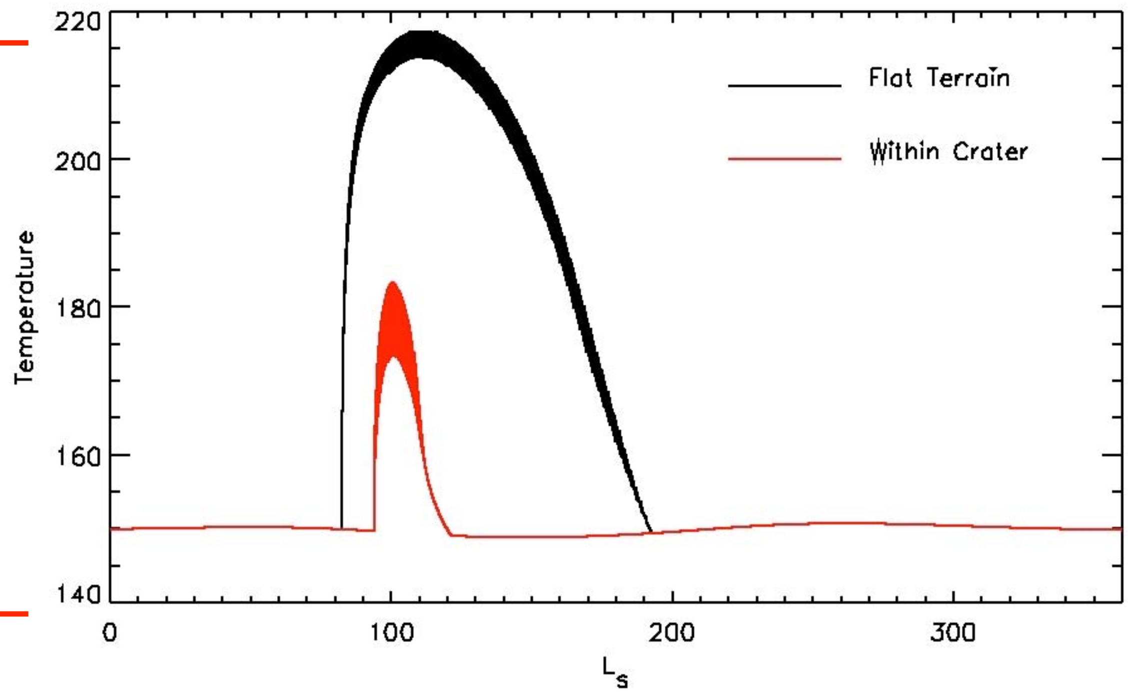


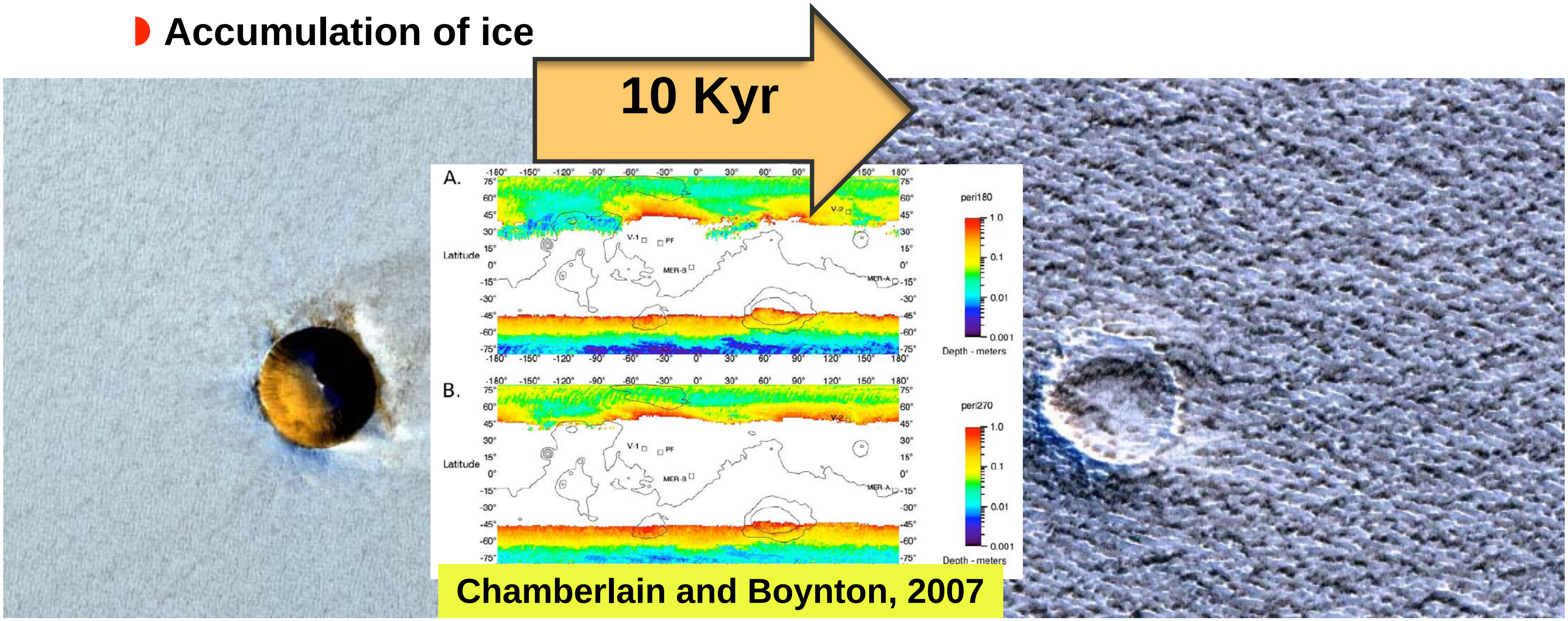
- **Much colder temperatures allows preferential frost accumulation**



- **NRC is an equilibrium surface**
  - **At least for the last ~10 Kyr**
  - **Crater infill rates 4-9mm/yr**

See *Banks et al.* for further description of the crater counts

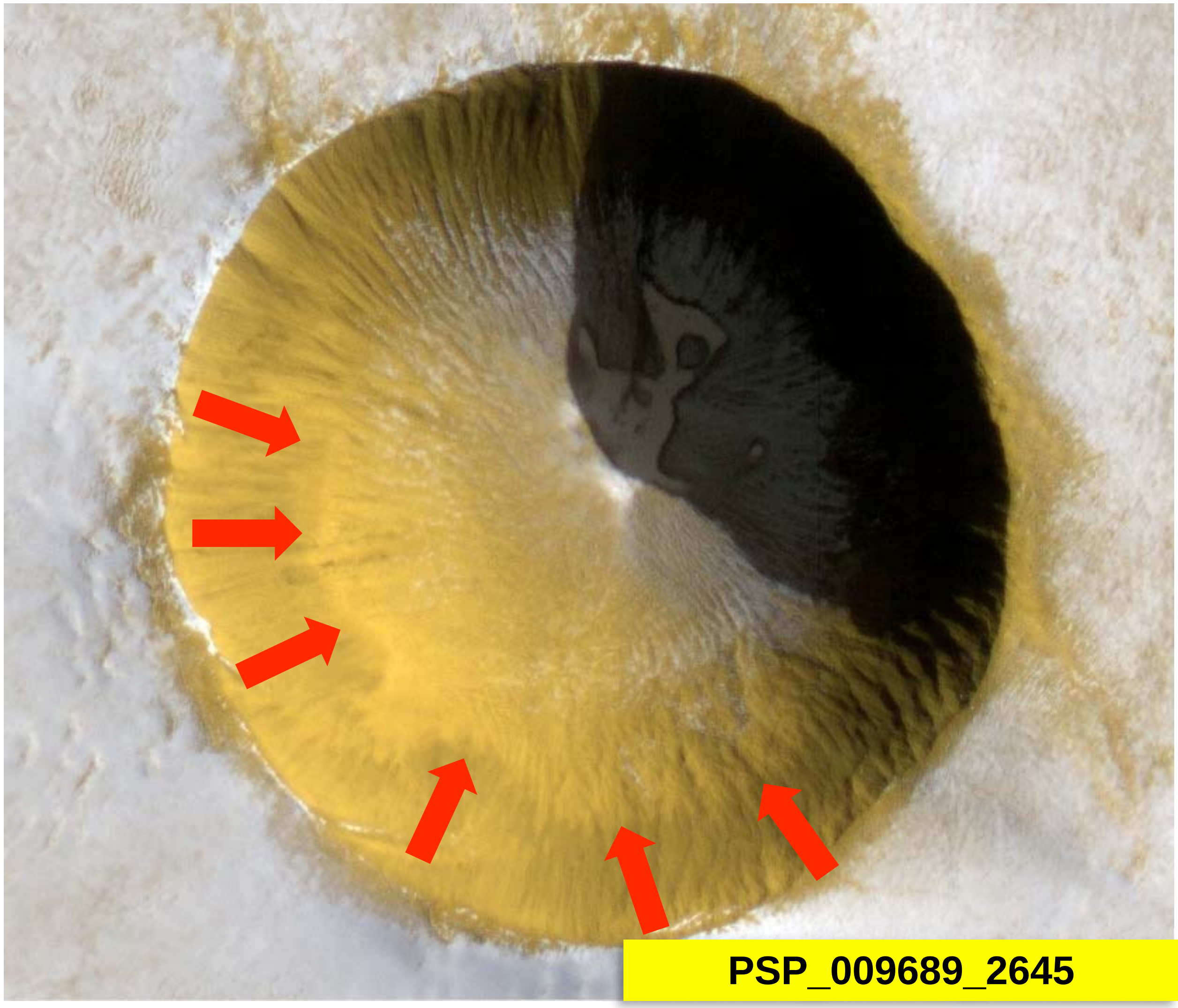
- **Polar cap accumulation rates ≠ crater infill rates**
  - **Modeling of crater degradation in progress**
    - **Ablation of upper walls**
    - **Slumping of lag deposit**
    - **Accumulation of ice**



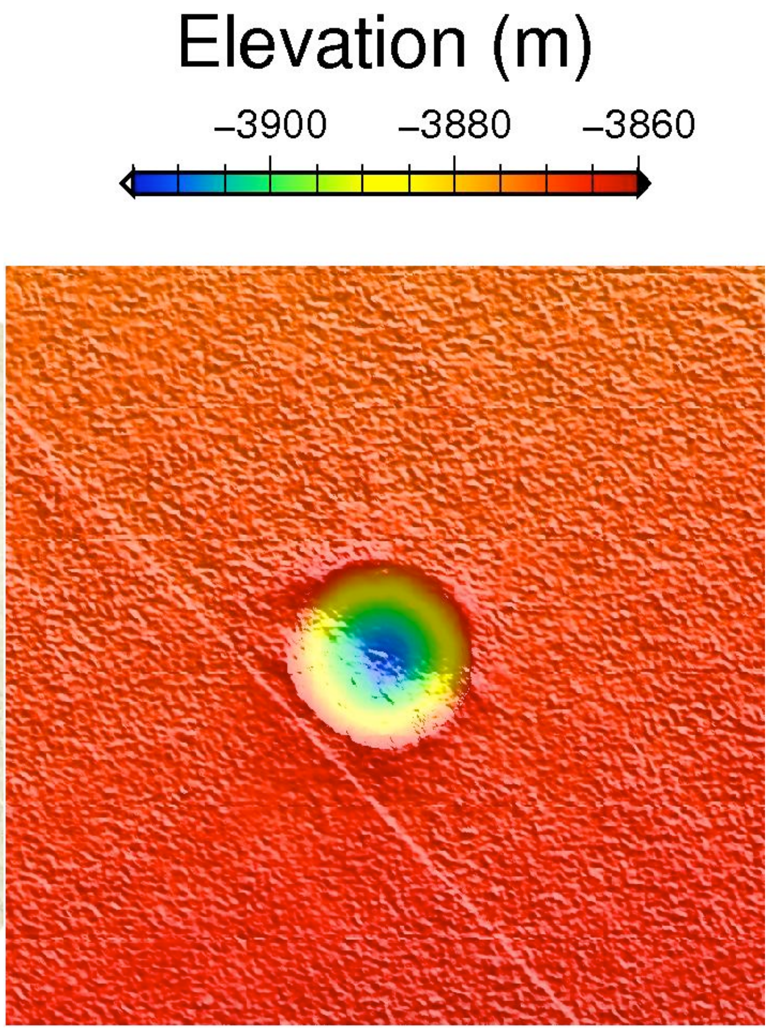
Chamberlain and Boynton, 2007

EXTRAS

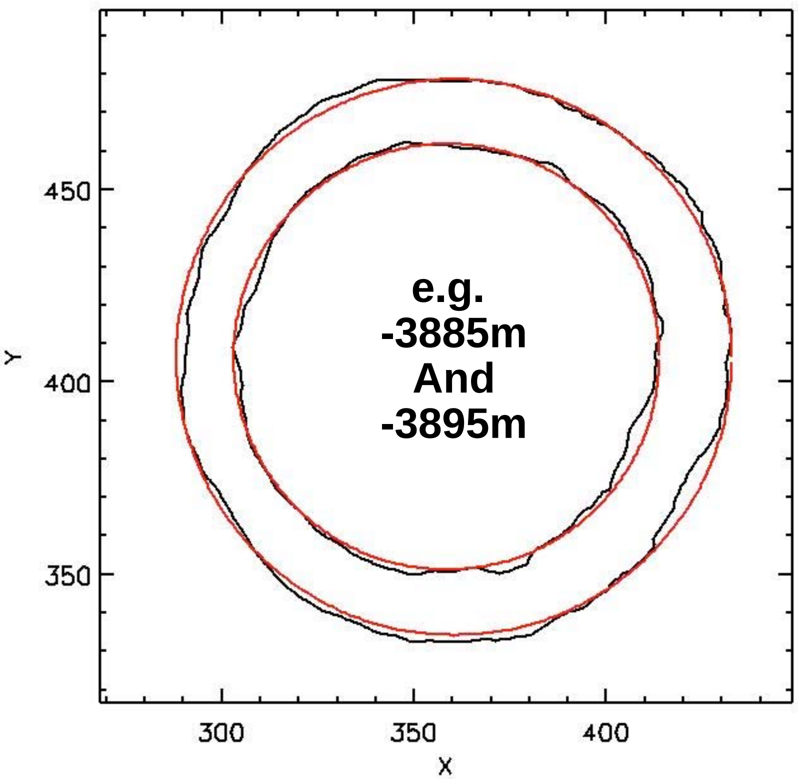
Conceptual model of crater degradation…



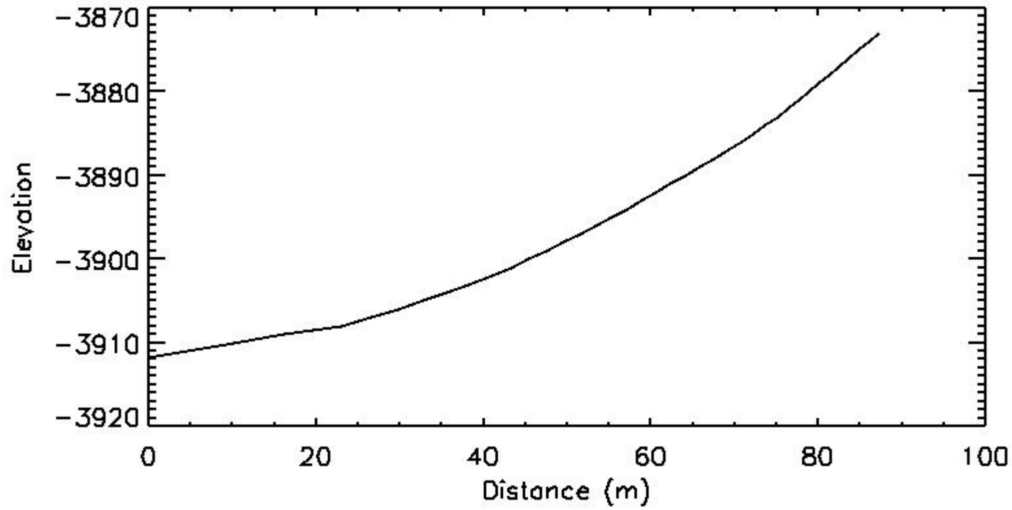
- **Stereo DEM available**
  - **1m posting**
  - **Accurate to ~1m**



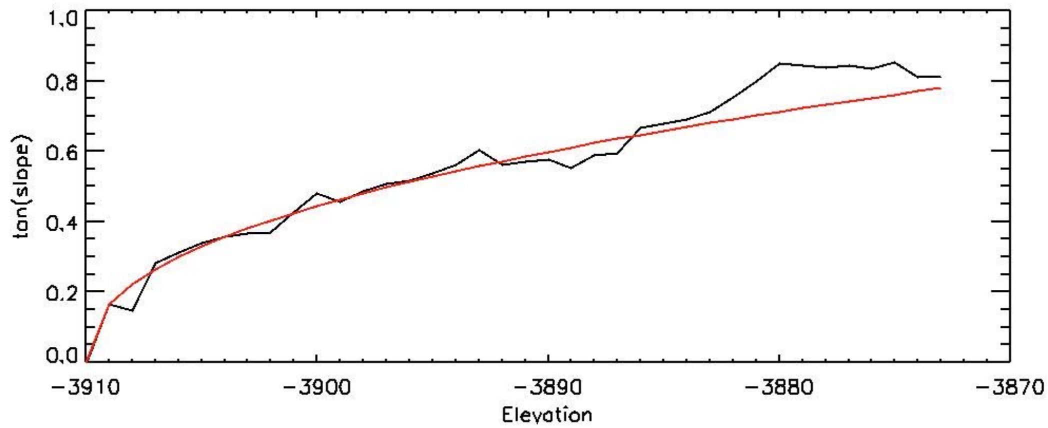
- Horizontal slices shows how the crater changes shape with elevation
  - Done every vertical meter
  - Fit a circle to the intersection of the DEM and slice



- **Crater shape looks pretty typical**
  - **Slopes increase with radius**

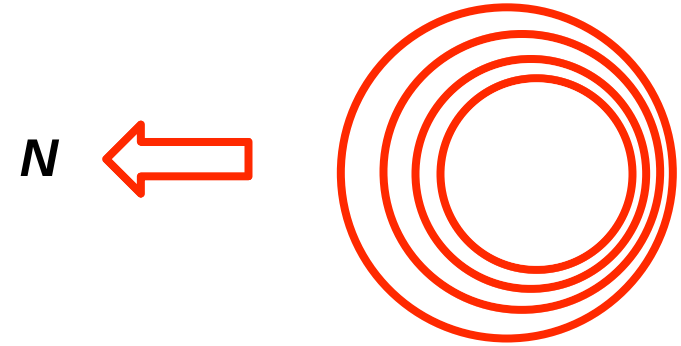


- **A closer look**
  - **Take Garvin's crater shapes**
    - **Fit to craters KMs in size**
  - **Slope proportional to $z^{0.43}$**
  - **Change in crater shape**



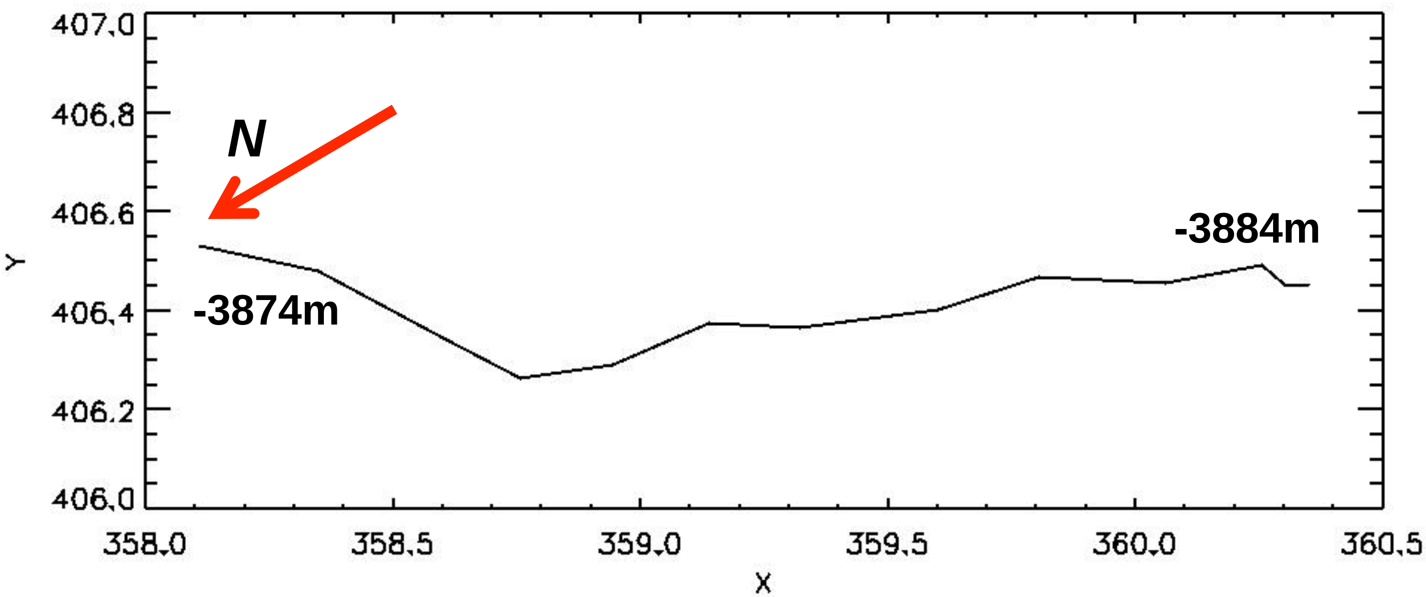
Polar Accumulation Modeled from Impact Craters

- **Evidence for ablation?**
  - **Slopes higher at higher elevations**
  - **More ablation higher up**
  - **More ablation on equatorward facing side**



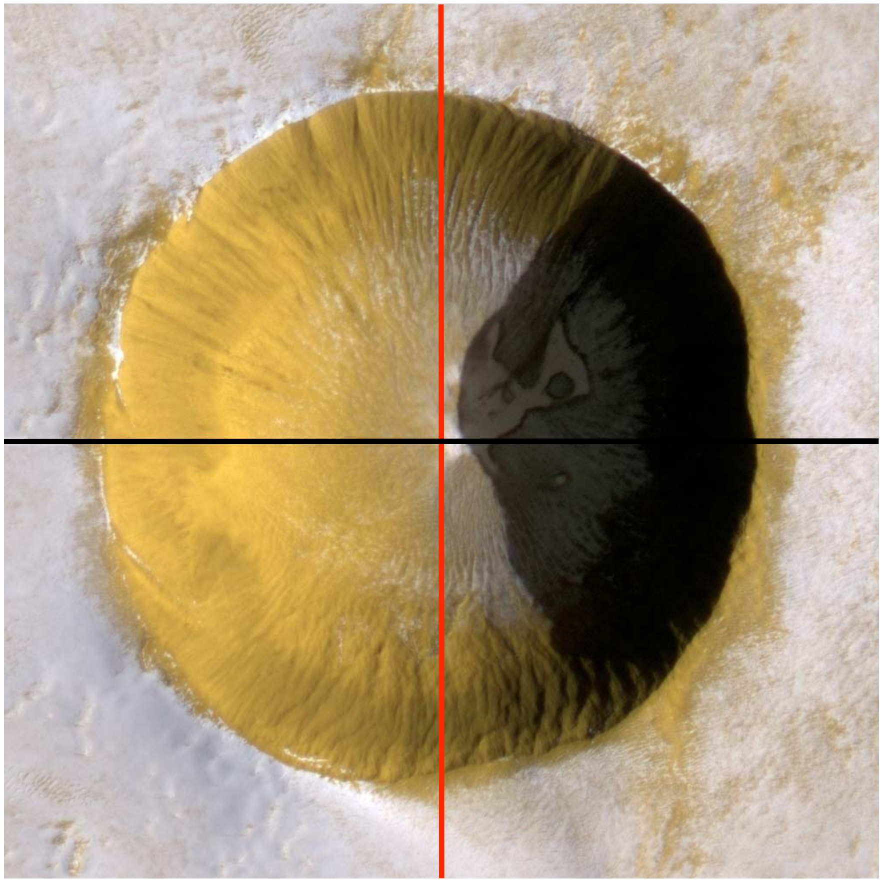
Crater expands asymmetrically

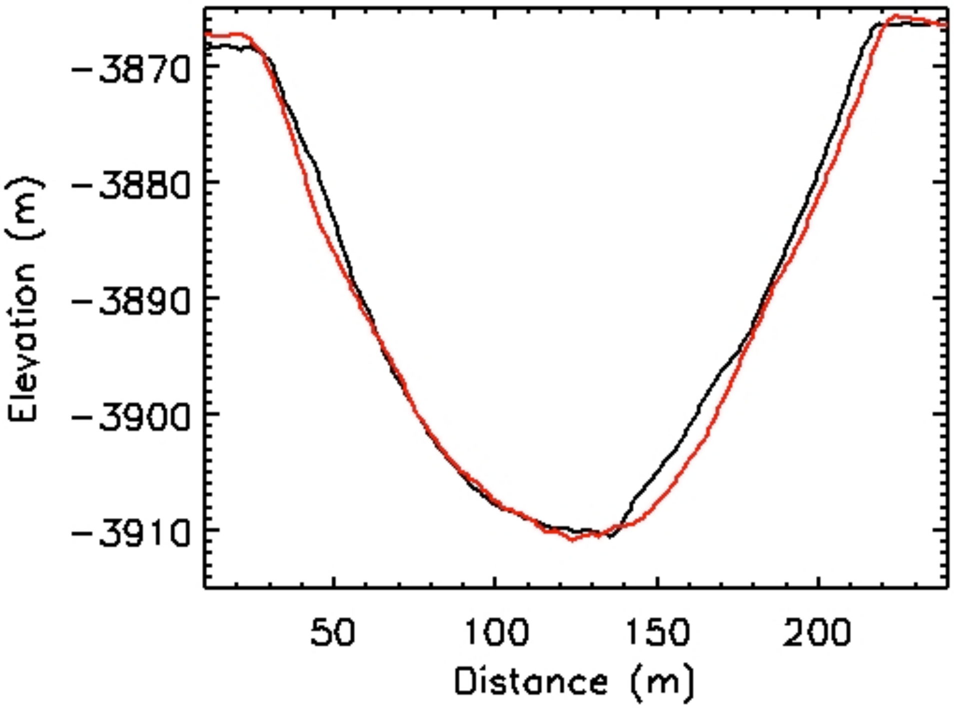
Center of crater moves northward



Crater walls are ablating outwards

South-facing walls by at least 5m more than North-facing walls





Elevation (m)
−3870
−3880
−3890
−3900
−3910
50
100
150
200
Distance (m)

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