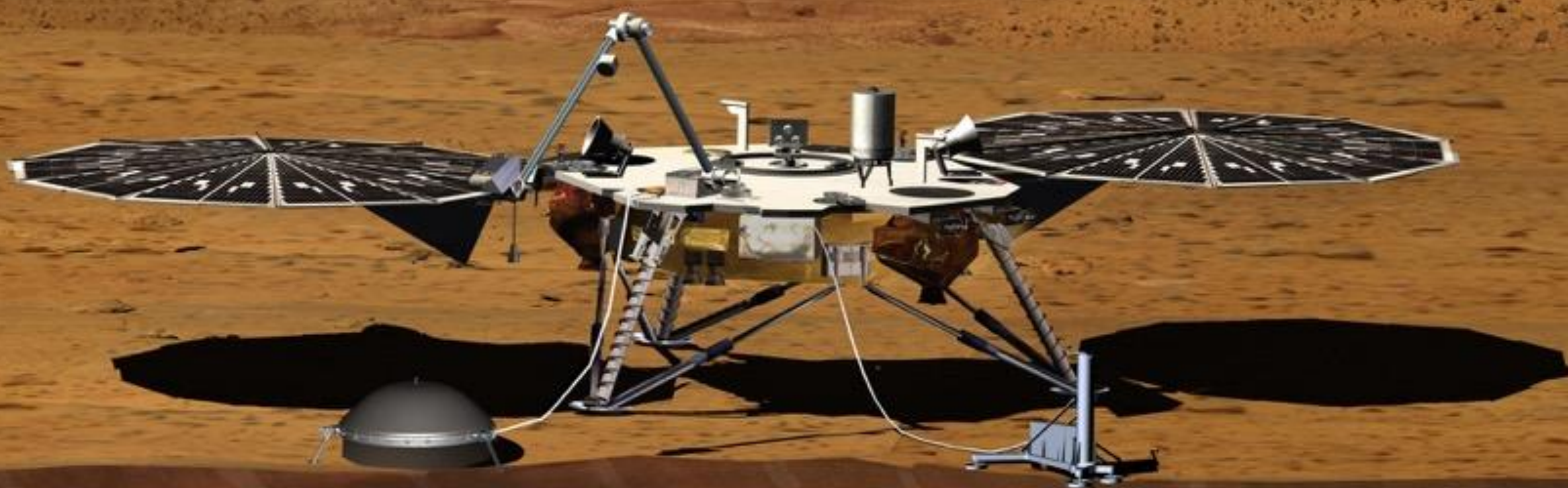
Landing Site Selection

InSight



Matt Golombek

InSight Co-I: Geology and Landing Site Lead

November 21, 2017

NASA's Museum Alliance and Solar System Ambassadors

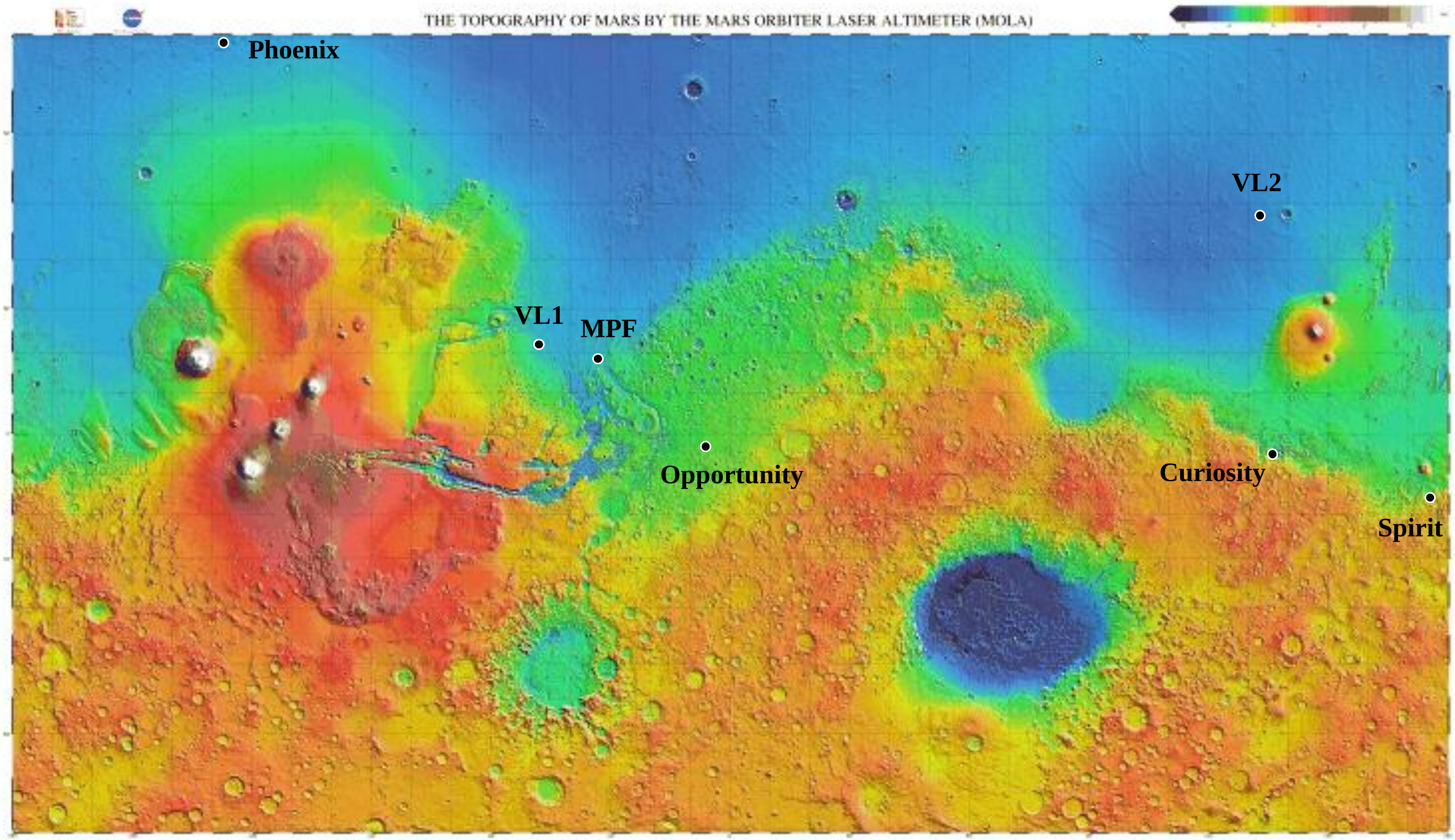
[redacted]

… Select a Landing Site?

- Why?
  - Because the Mission will Fail if Don’t Land Safely
  - Because the Mission Costs a Lot of Time, Energy & Money
- When?
  - During Project Development
  - Spacecraft Capabilities Change
- How?
  - Map Engineering Constraints onto Mars
  - Define Acceptable Sites
  - Gather Information to Certify Sites
- What?
  - Smooth, Flat “Boring” Rock Free Plain - Safe for Landing [and Roving]
  - Address Science Objectives of Mission
  - Complies with Planetary Protection
- Five Selection Efforts for Successful Missions in Modern Era – Past 20 Years
  - MPF – 1997 MER – 2003 PHX – 2008 MSL – 2012
- Why Important?
  - Ground Truth to Remote Sensing Data - Interpret Surfaces & Material on Mars
  - Critical for Mars Exploration Program
- Why would someone do this for a living???
  - Limited places to work (just JPL), Limited work (when lander)

Landing Sites on Mars

Latitude & Elevation – Low & Equatorial



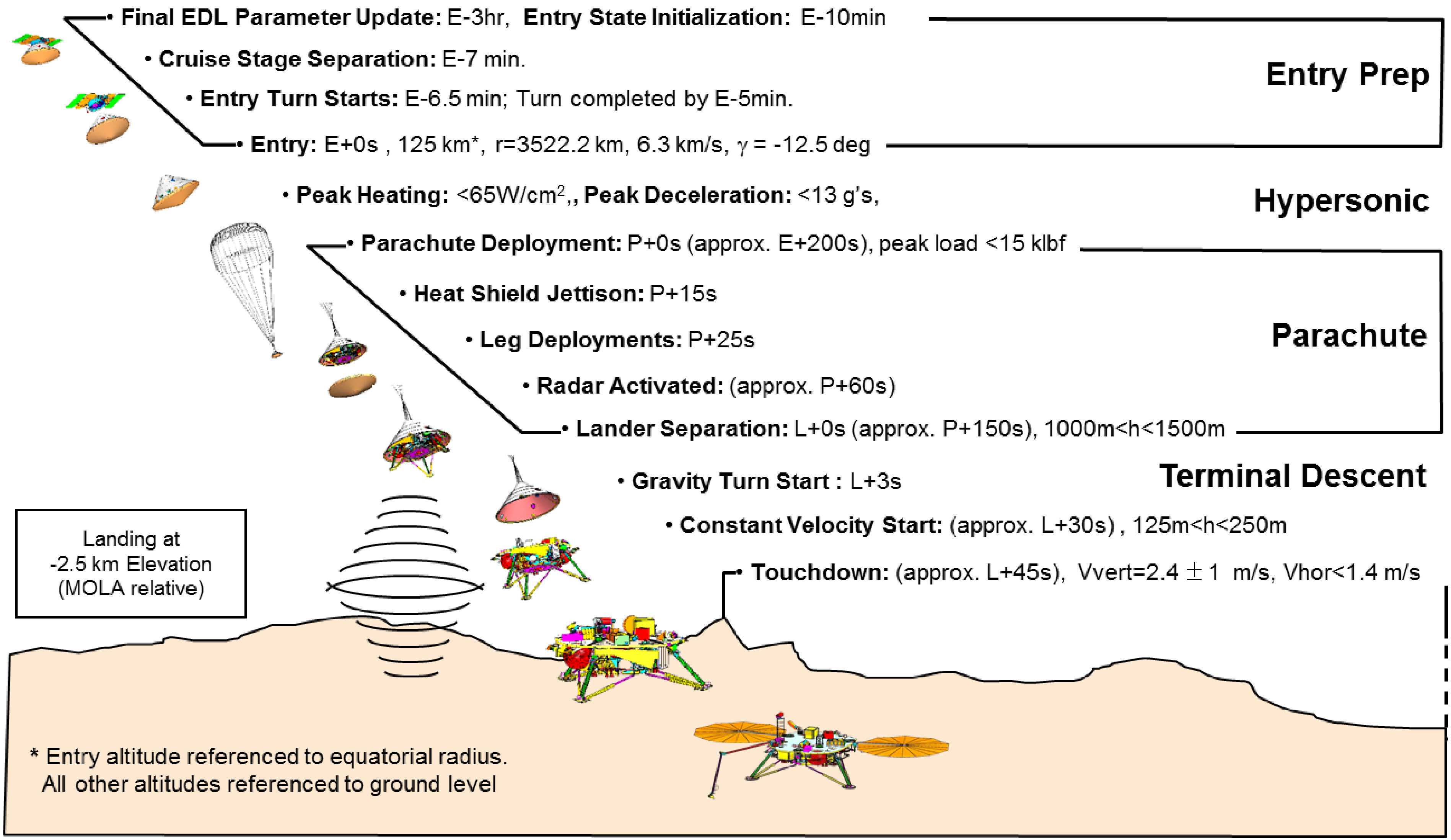
Elevation – Atmosphere for EDL

Latitude – Power, Thermal Management

InSight Landing Site Selection History

- GEMS Discovery Proposal – Look in Elysium Planitia – 9/10
  - Ref Ellipse at 0.83°S, 141.48°E [near E14], Met Engineering Constraints
- CSR at end of Phase A: Selected Elysium – 3/12
  - Identified 16 Ellipses – first few HiRISE images; NASA Hq Participated in Review; MOA with MEP
  - InSight Selected as Discovery Mission, 8/12; Landing Site Selection Part of Every Major Project Review
  - Resolve Communication w/MSL & Image on Same Pass, 6 Mo
  - 90% CTX Coverage in <1 yr; Since - ~1 HiRISE per week
- First Landing Site Workshop – IGPP, Paris 6/13
  - Identified 22 Ellipses – CTX Terrain Mapping; HiRISE Samples (20)
- First Downselection – 7/13 - Selected 4 Ellipses
- Council of Terrains; Council of Atmospheres, 2/14
  - Development Surface Data Products Landing; Reference Atmospheres
- Second Landing Site Workshop – JPL, 9/14
  - Full Discussion of Everything Known About Sites
  - Peer Reviewed Data Products
- Second Downselection – 1/15, Provisionally Selected E9
  - Confirmed Selection of E9, Eliminated Backups 5/15
- Third Landing Site Selection Workshop – JPL, 9/30/15
  - Full Discussion of All Data Products
  - Review of Simulation Results
- Independent Peer Review and InSight Project Landing Site Certification – JPL, 10/15/15
- Planetary Protection Review – JPL, 10/19/15 - No Water or Ice within 5 m of Surface
- NASA Headquarters Briefing, 12/14/15
- No 2016 InSight Launch – Selected for 2018 Launch
- Atmospheric Pressure ~Same for 2018 Type ! Launch - No Change to Landing Site

InSight EDL



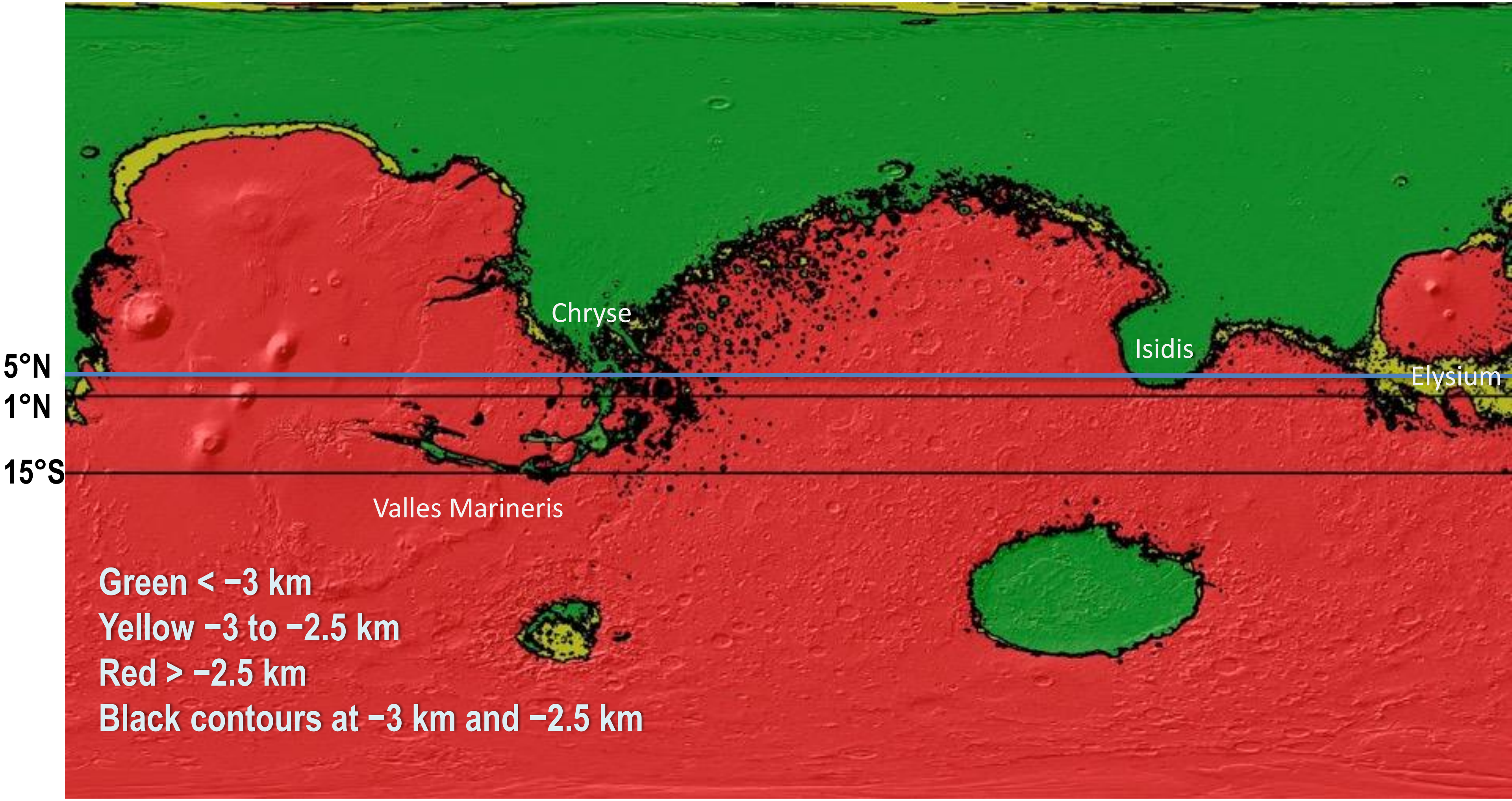
• Final EDL Parameter Update: E-3hr, Entry State Initialization: E-10min
• Cruise Stage Separation: E-7 min.
• Entry Turn Starts: E-6.5 min; Turn completed by E-5min.
• Entry: E+0s , 125 km*, r=3522.2 km, 6.3 km/s, γ = -12.5 deg
Entry Prep
• Peak Heating: <65W/cm2,, Peak Deceleration: <13 g's,
Hypersonic
• Parachute Deployment: P+0s (approx. E+200s), peak load <15 klbf
• Heat Shield Jettison: P+15s
• Leg Deployments: P+25s
• Radar Activated: (approx. P+60s)
• Lander Separation: L+0s (approx. P+150s), 1000m<h<1500m
Parachute
• Gravity Turn Start : L+3s
Terminal Descent
• Constant Velocity Start: (approx. L+30s) , 125m<h<250m
• Touchdown: (approx. L+45s), Vvert=2.4 ± 1 m/s, Vhor<1.4 m/s
Landing at
-2.5 km Elevation
(MOLA relative)
* Entry altitude referenced to equatorial radius.
All other altitudes referenced to ground level

Landing Site Constraints

- **Latitude:** 15°S to 5°N: Sufficient Solar Power Margins
  - 5°N to 2°S Elysium Planitia; Later 3°N-5°N
- **Elevation:** <−2.5 km MOLA: Sufficient Atmosphere for EDL
- **Ellipse Size:** 139 km × 27 km [99.5% ellipse]; 130 x 27 km Reference Ellipse
- **Thermal Inertia:** >100−140 J m^{-2} K^{-1} $s^{-1/2}$
  - Avoid surfaces with thick dust that is not loading bearing
  - Prefer ~200 J m^{-2} K^{-1} $s^{-1/2}$ for uncemented or poorly cemented soil
  - Radar reflective surface
- **Rock Abundance:** <10%
  - 99% Safe Landing and Opening Solar Panels
- **Smooth Flat Surface:** No large relief features
  - Slopes <15° for Safe Touchdown and Radar Tracking (1-5 m & 84 m)
- **Deploy Instruments: [<10% Rock Abundance, <15° Slope]**
- **Broken up regolith >5 m thick:** Hesperian Cratered Surface
  - Penetration of the Mole

No Other Science Requirements: Just Land Safely

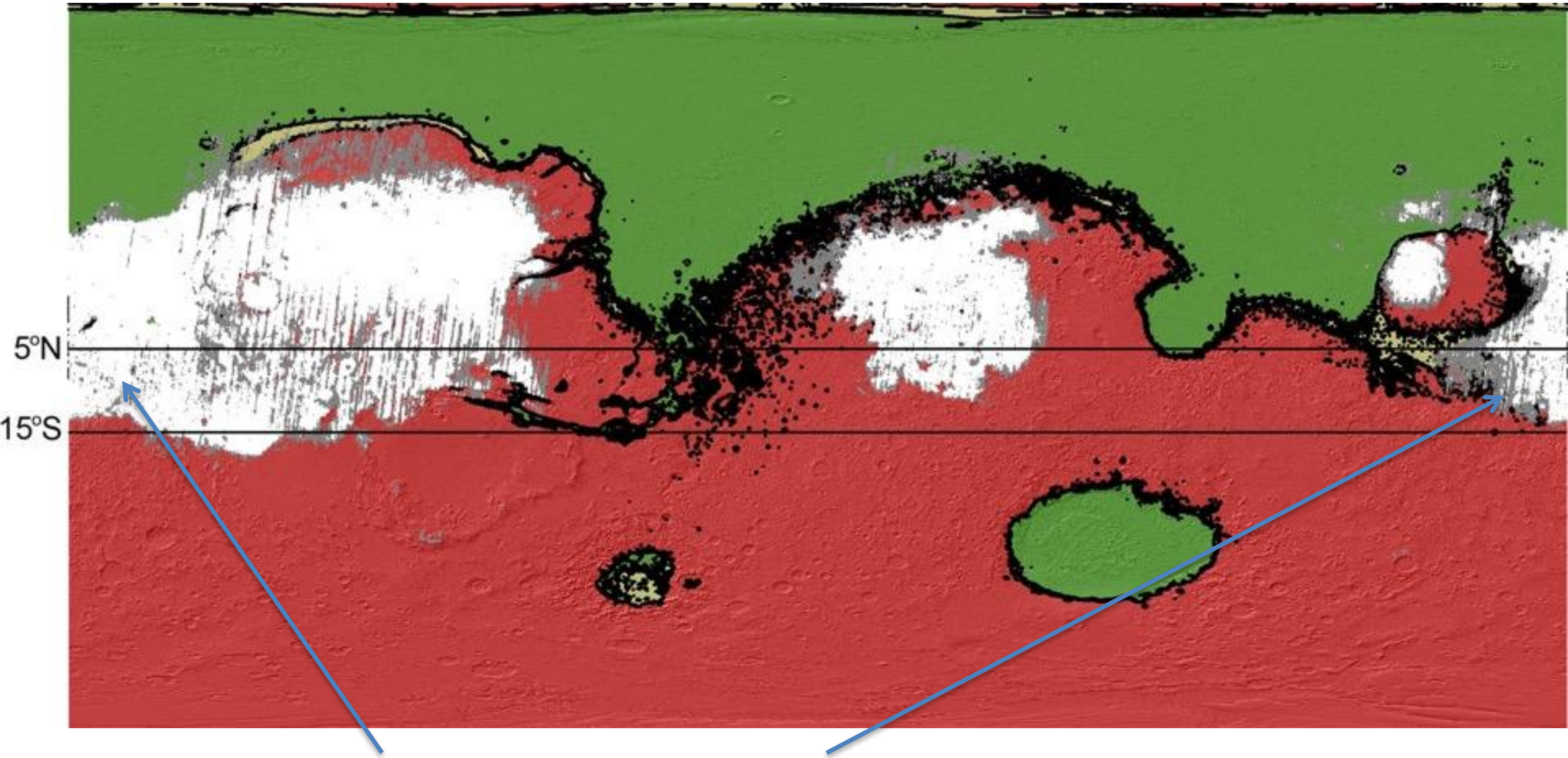
Global Latitude and Elevation



Valles Marineris & S Chryse Outflow
S Isidis Planitia
Both Rocky
Elysium

Expect S Chryse and Isidis Windy
GCMs Storm Tracks High N Lat.
Valles Marineris Canyons Windy
S Elysium Low Winds

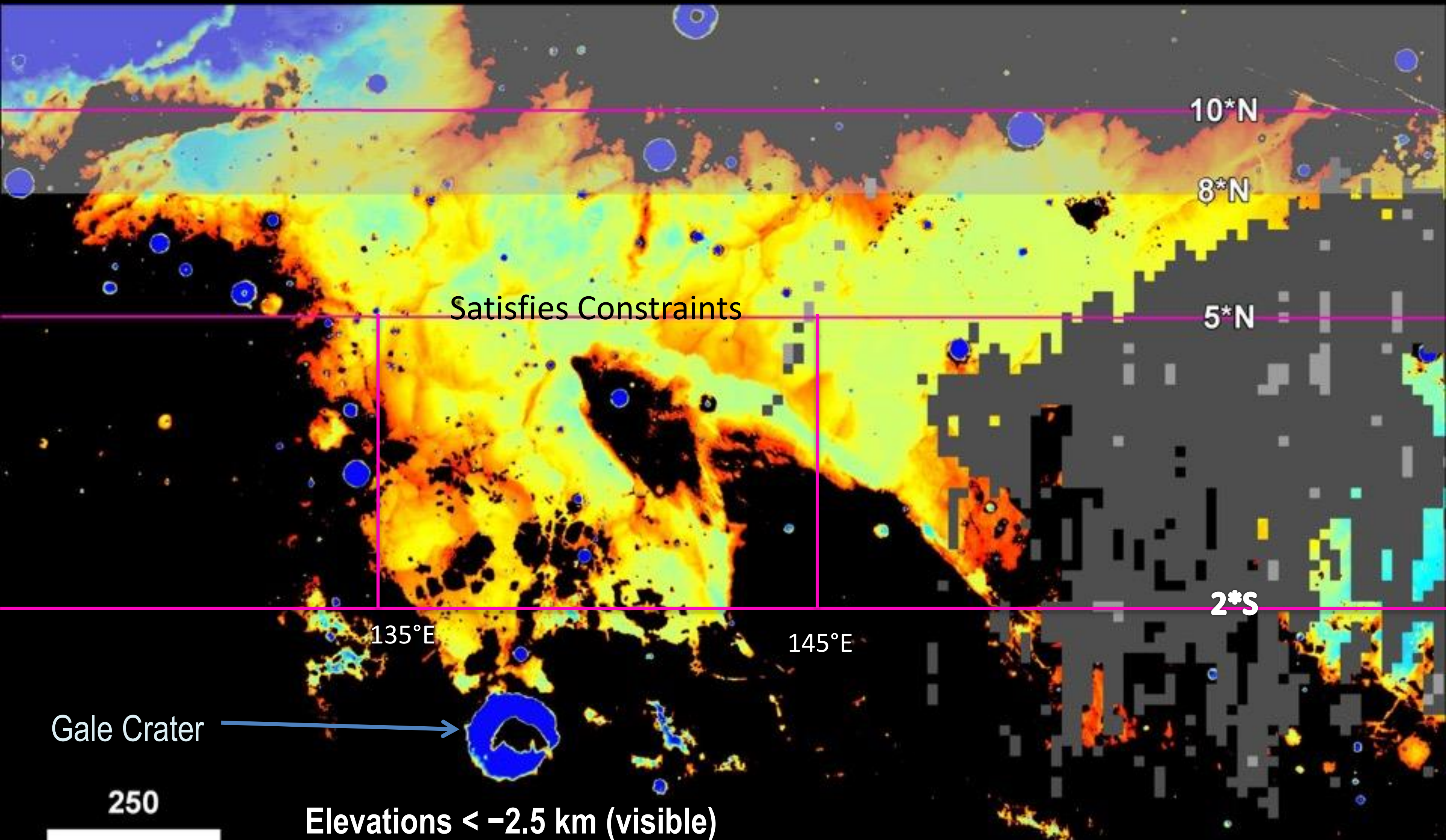
Thermal Inertia



Amazonis and E Elysium Planitiae too dusty

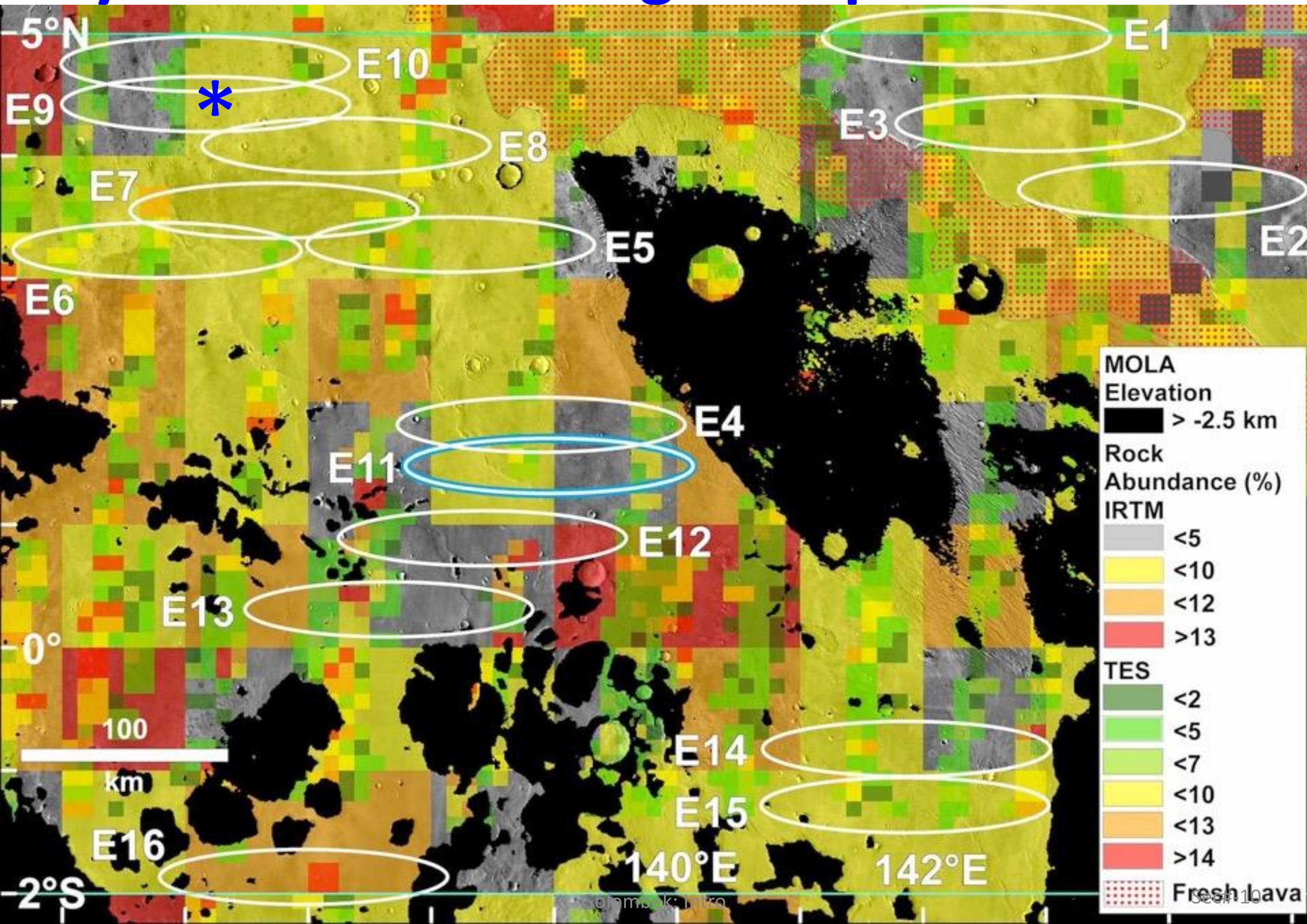
TI <100 J m^{-2} K^{-1} $s^{-1/2}$ mask in white
TI <140 J m^{-2} K^{-1} $s^{-1/2}$ mask in grey

Elysium Planitia Elevation, Latitude & Thermal Inertia



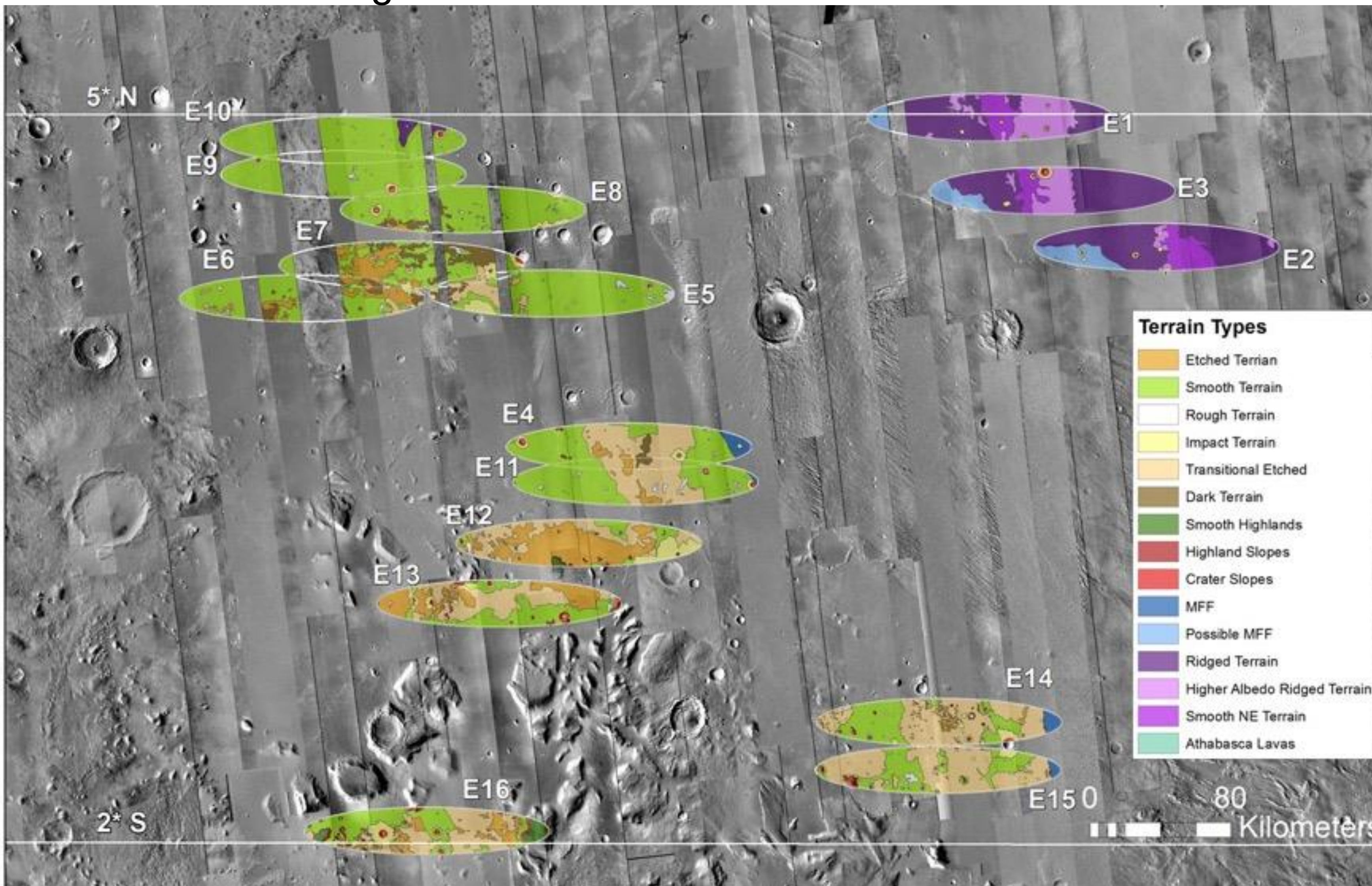
Elevations < −2.5 km (visible)
Thermal inertia < 100 $Jm^{-2}K^{-1}s^{-1/2}$ (light gray mask)
Thermal inertia <140 $Jm^{-2}K^{-1}s^{-1/2}$ (dark gray mask)

Elysium Planitia InSight Ellipses at CSR 5/12



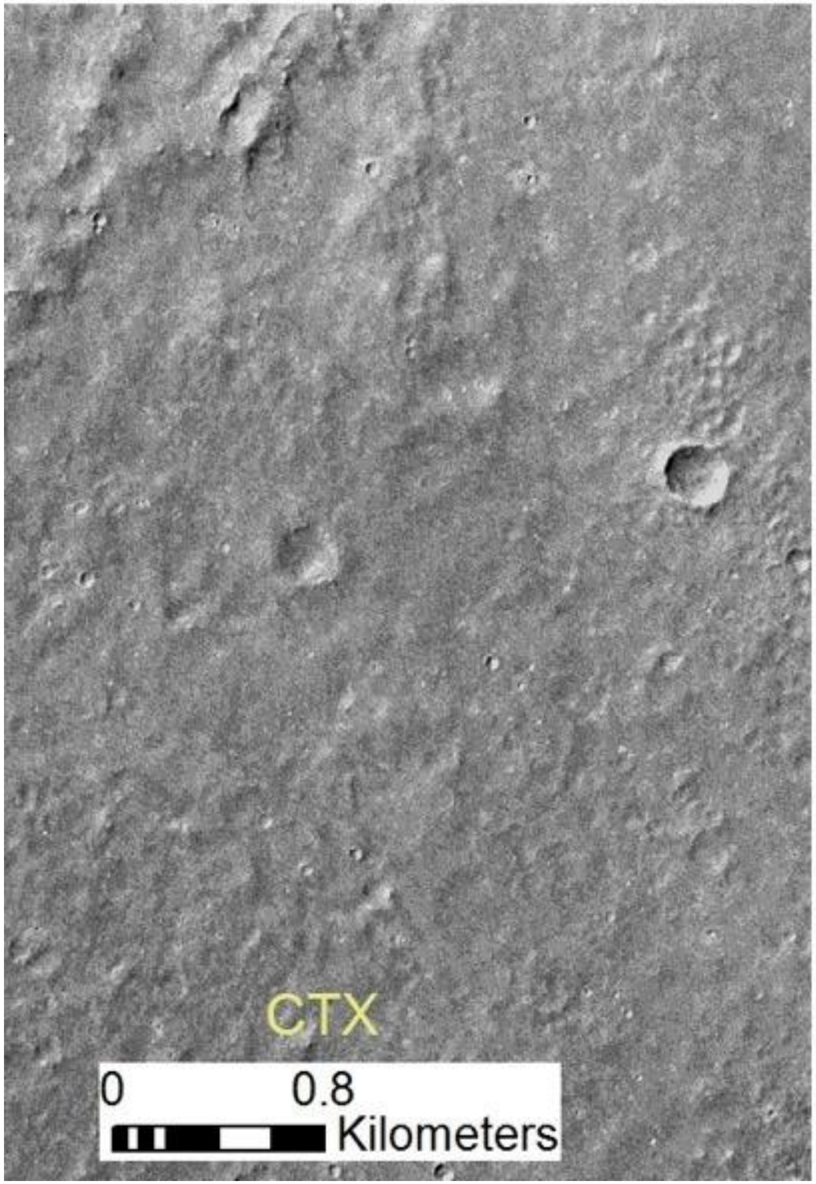
Terrain Mapping at 1st Workshop 6/13

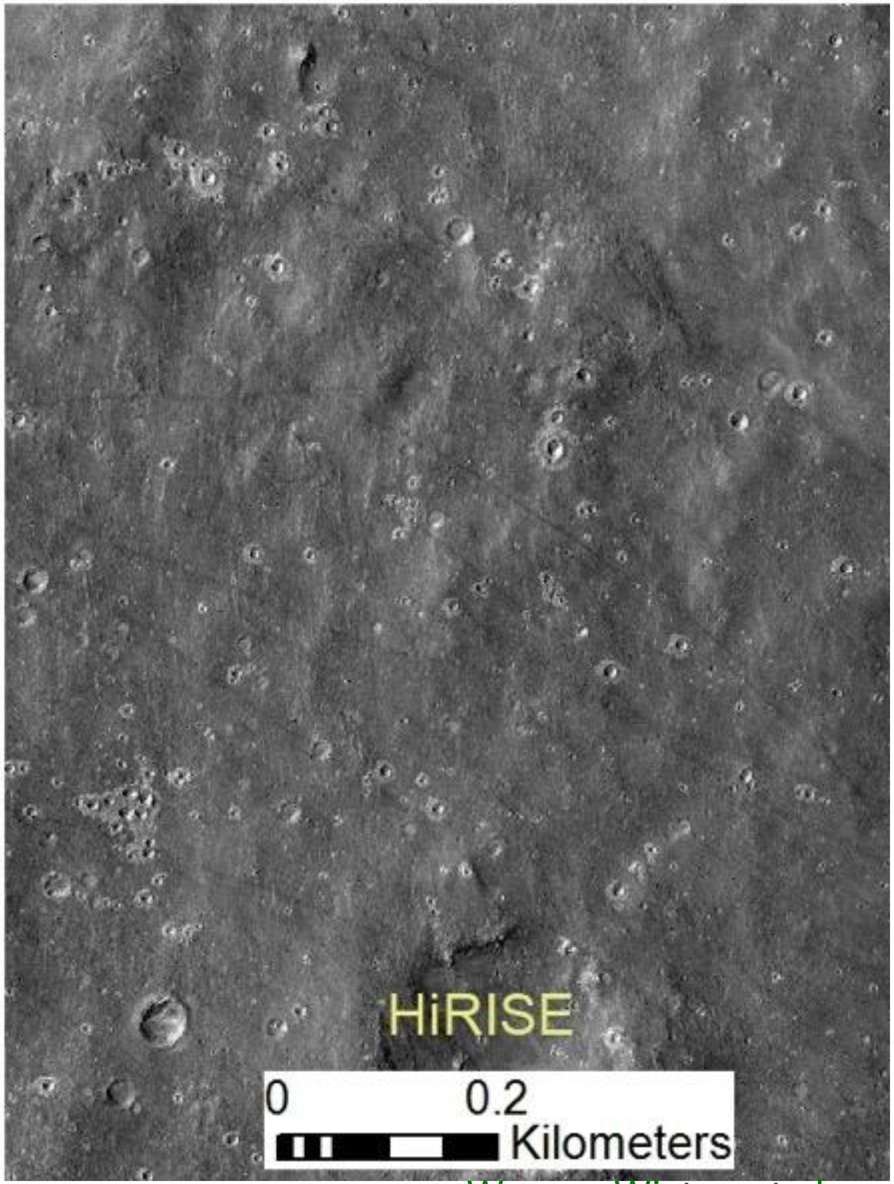
- Mapping within ellipses (1:40,000)
- ~90% CTX coverage and 4 HiRISE



persons may require an export authorization.

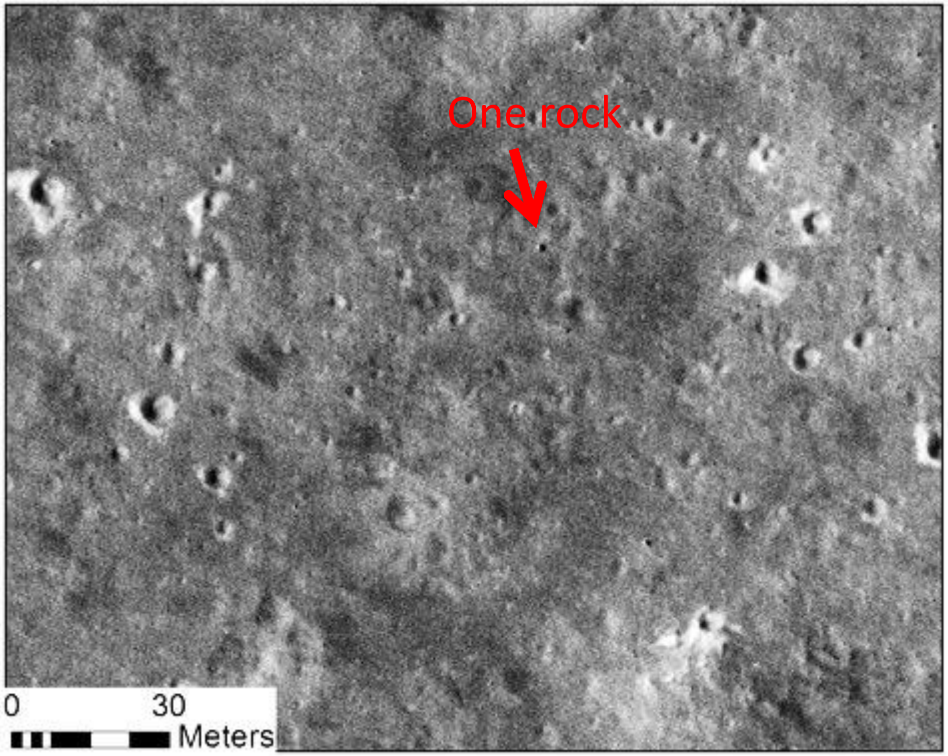
Smooth Terrain: CTX + HiRISE

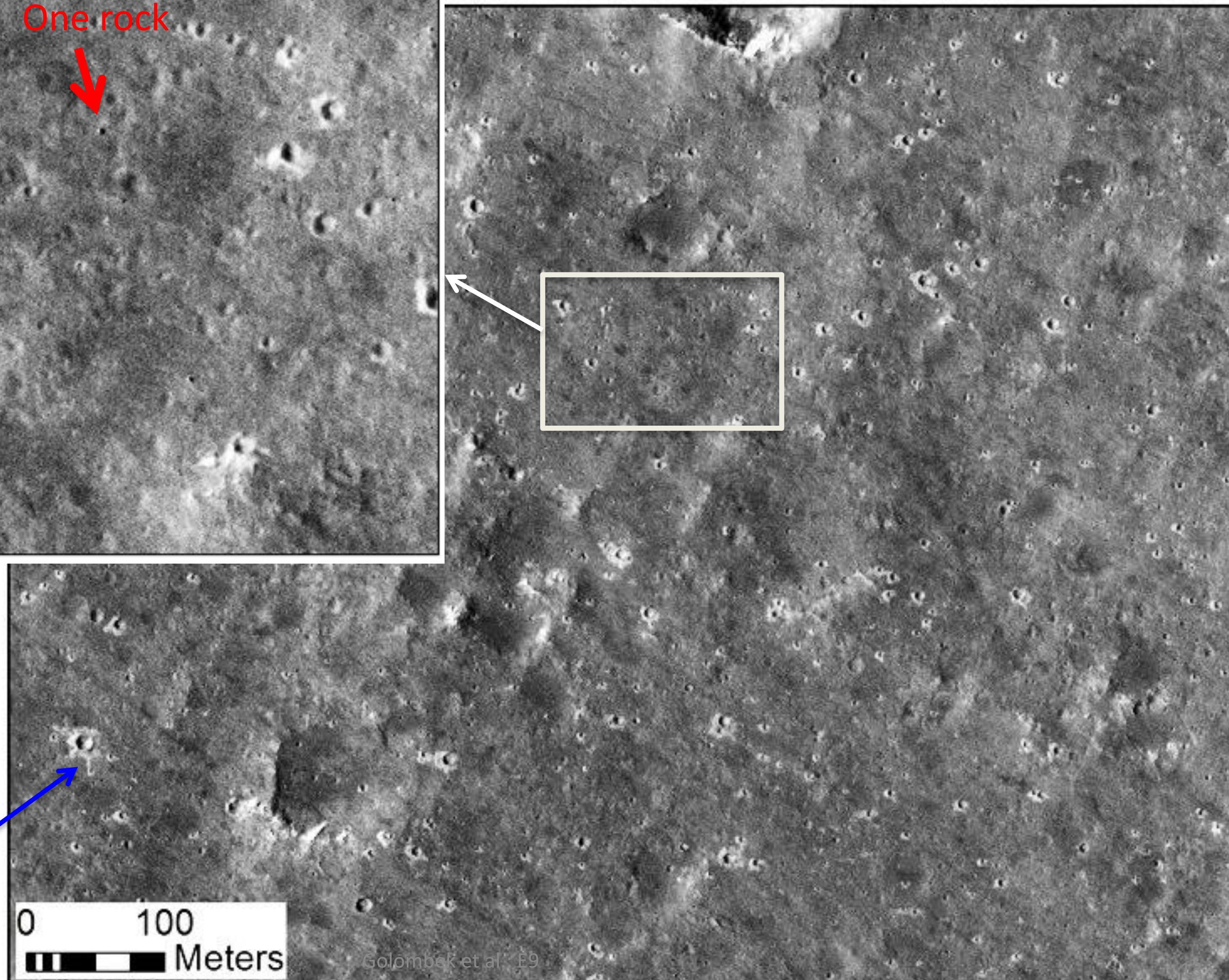




Warner, Wigton et al.

Smooth Terrain: HiRISE



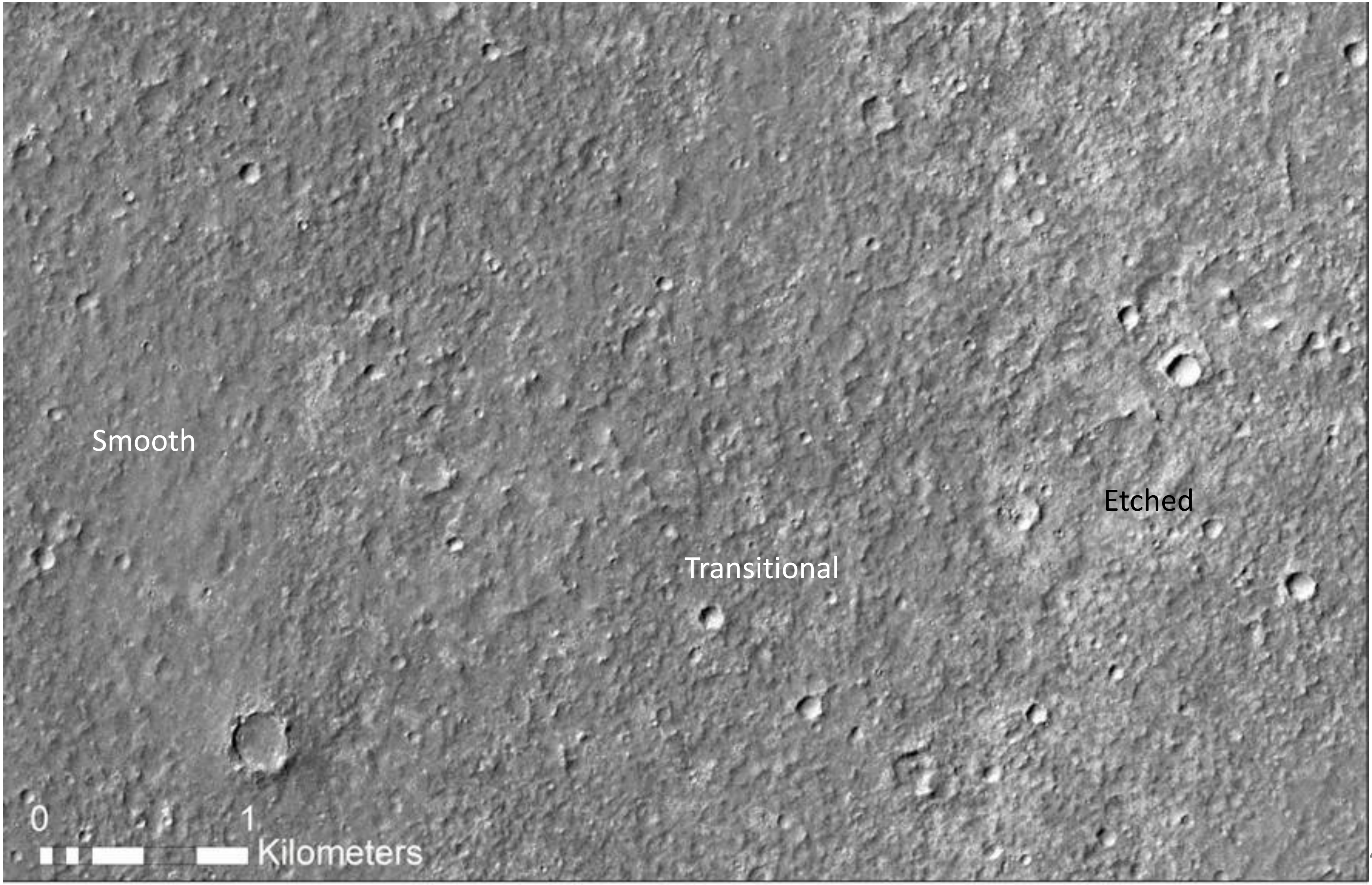


Exceptionally Benign
Very Low Slopes
Few % Rock Abundance
Small Secondary Craters

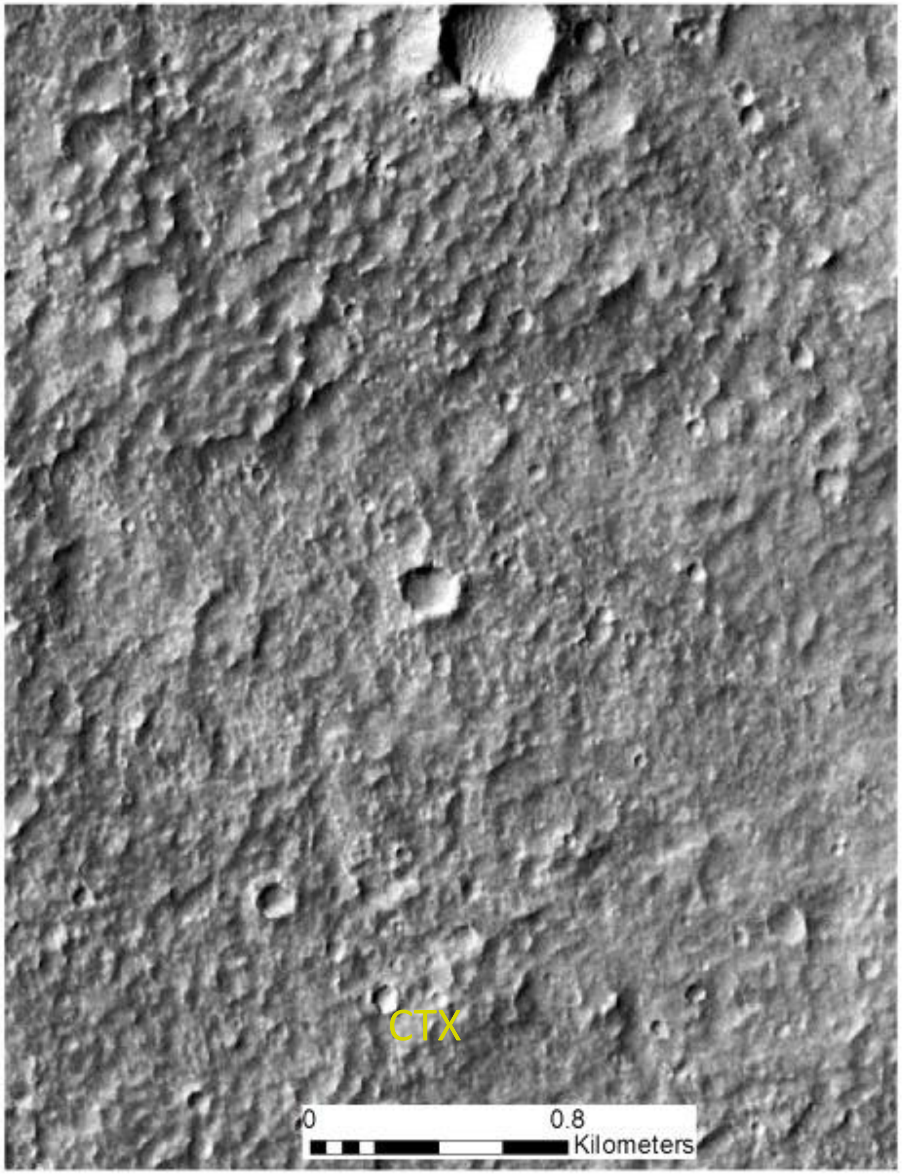
Transitional Terrain: CTX

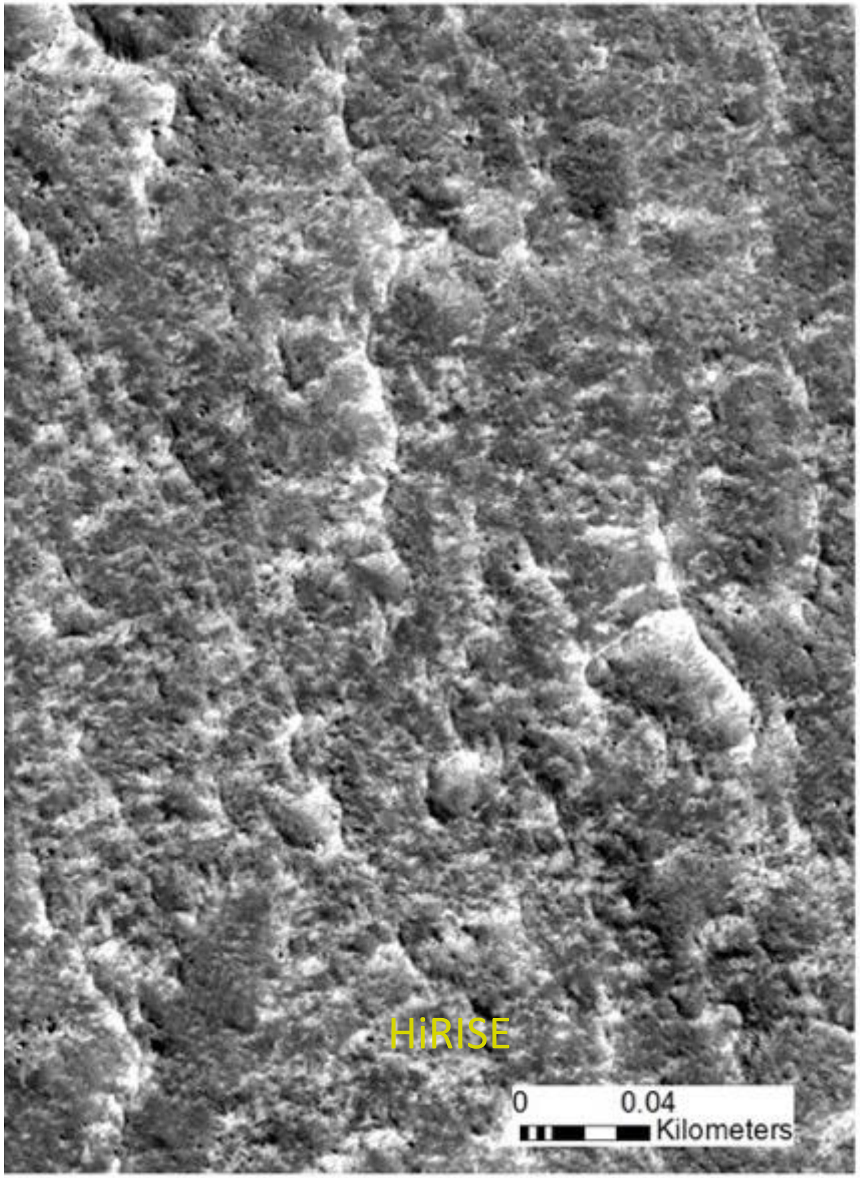
-Intermediate albedo, roughness, and thermal signature.
-Transitional between smooth and etched terrain.

Warner, Wigton et al.



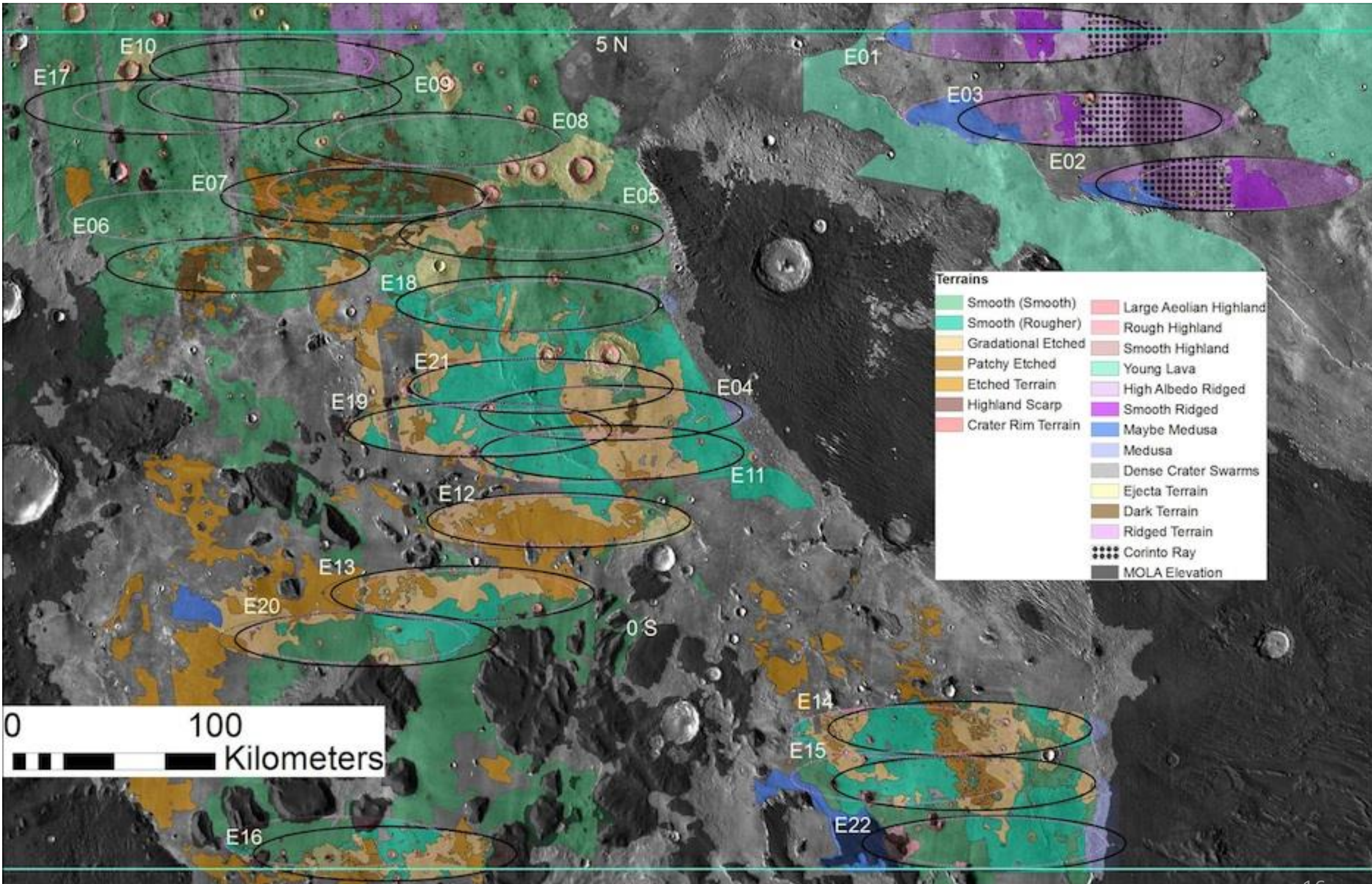
Etched Terrain: CTX + HiRISE





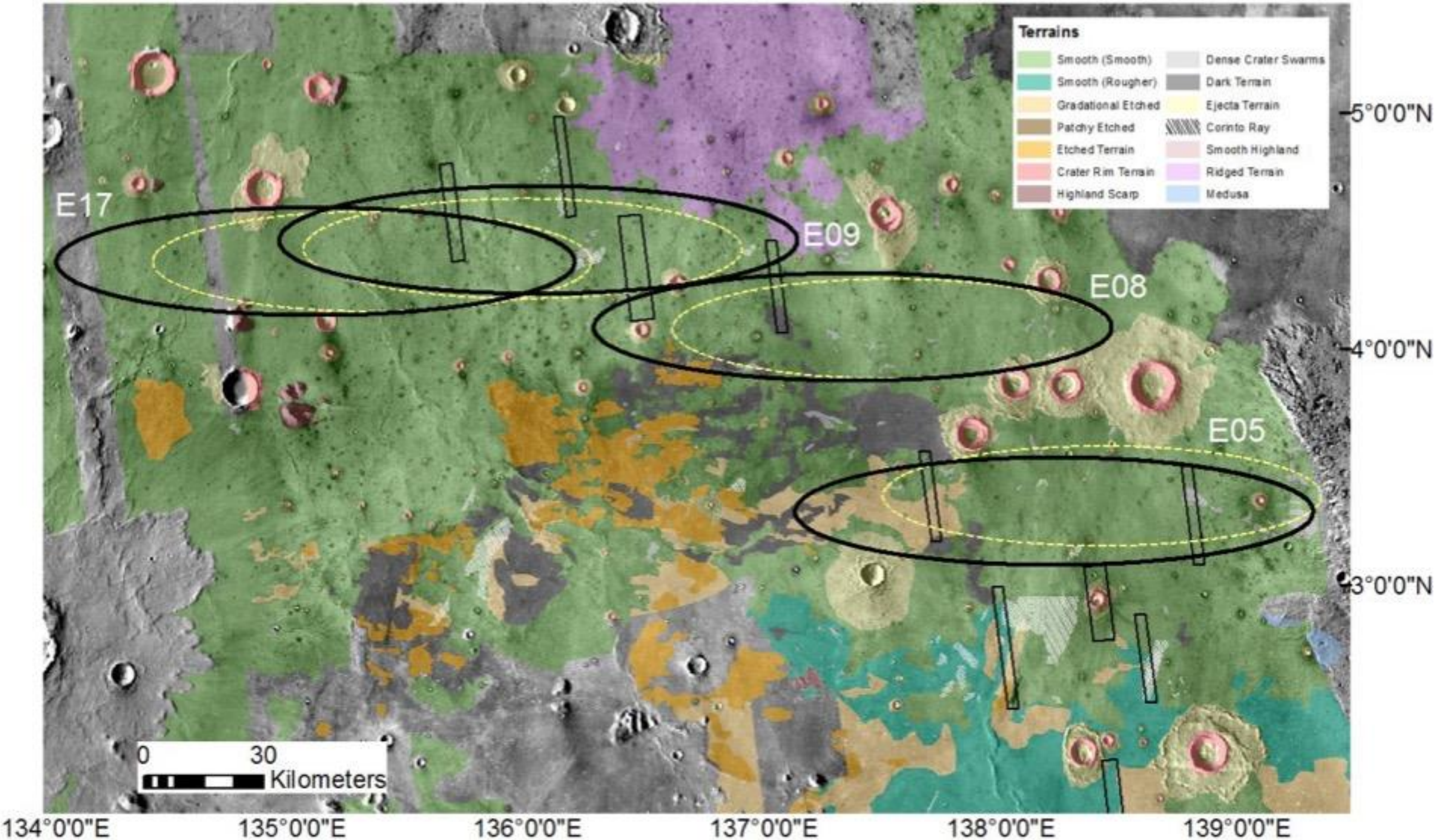
Warner, Wigton et al.

Terrain Map CTX 1st Downselection 7/13



Added Ellipses E17 – E22

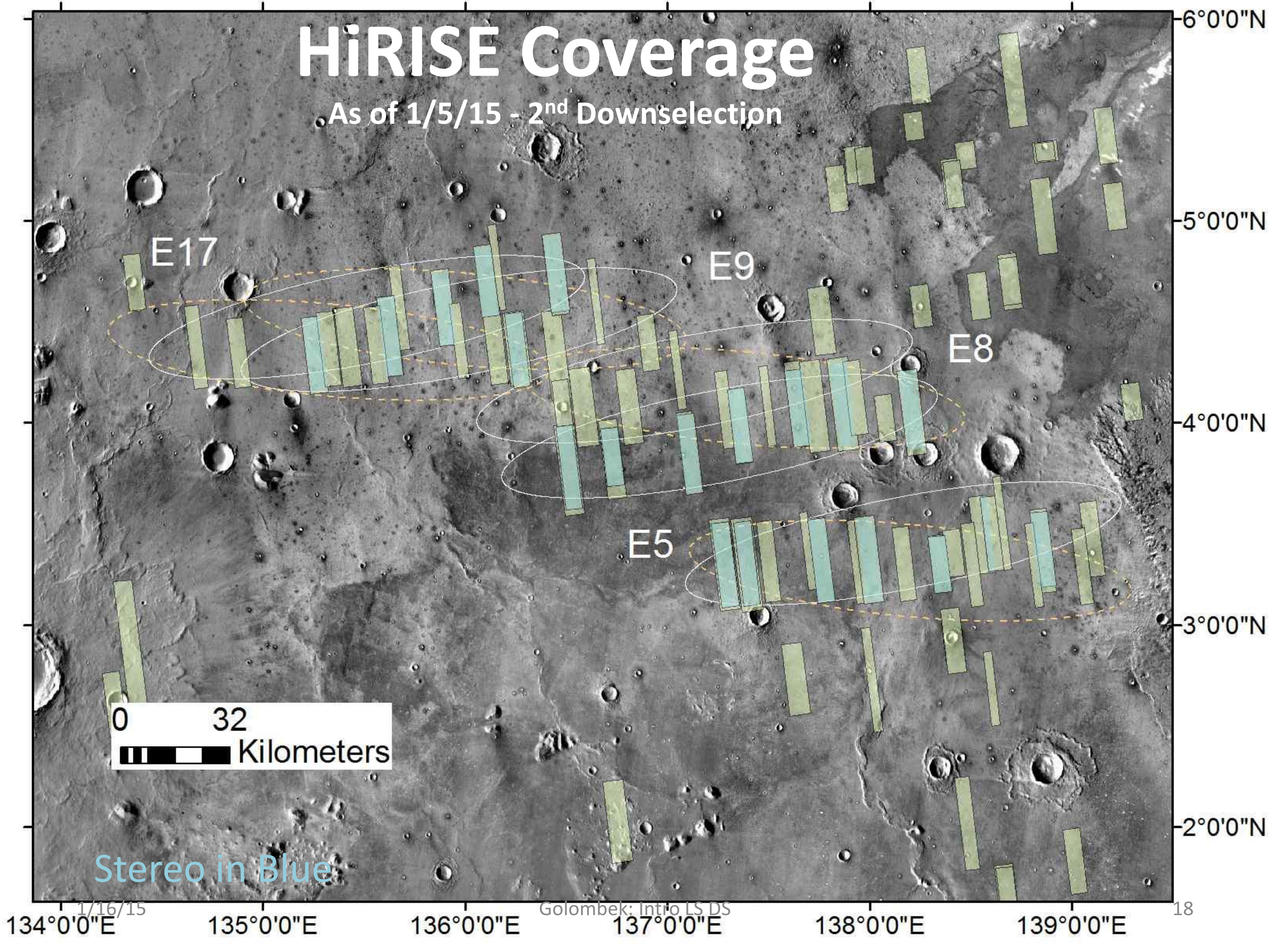
Final Four Ellipses 7/13



HiRISE Images at PDR

HiRISE Coverage

As of 1/5/15 - 2nd Downselection



Terrain Map

with 10 HiRISE DEMs

2nd Downselection 1/15

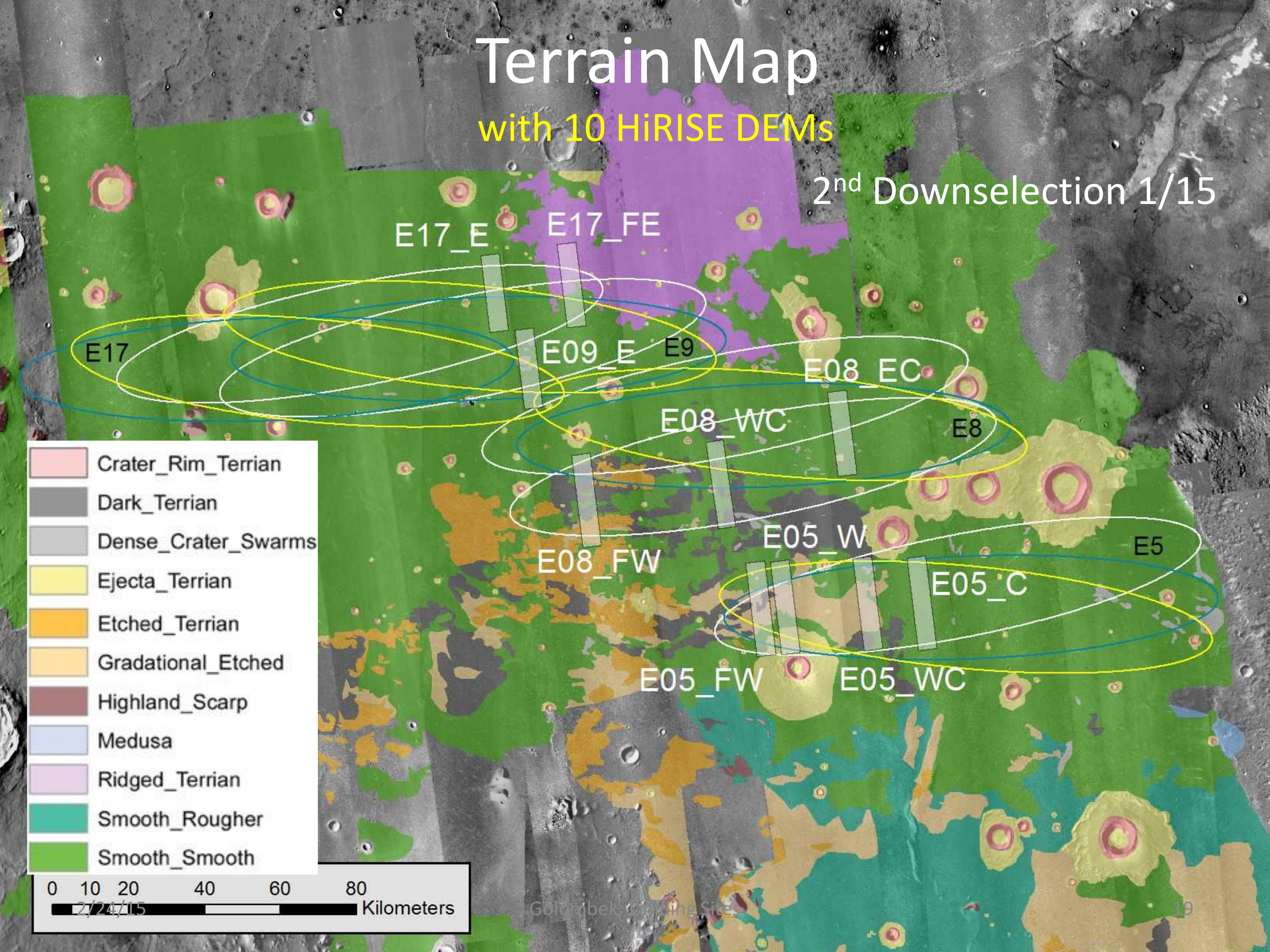
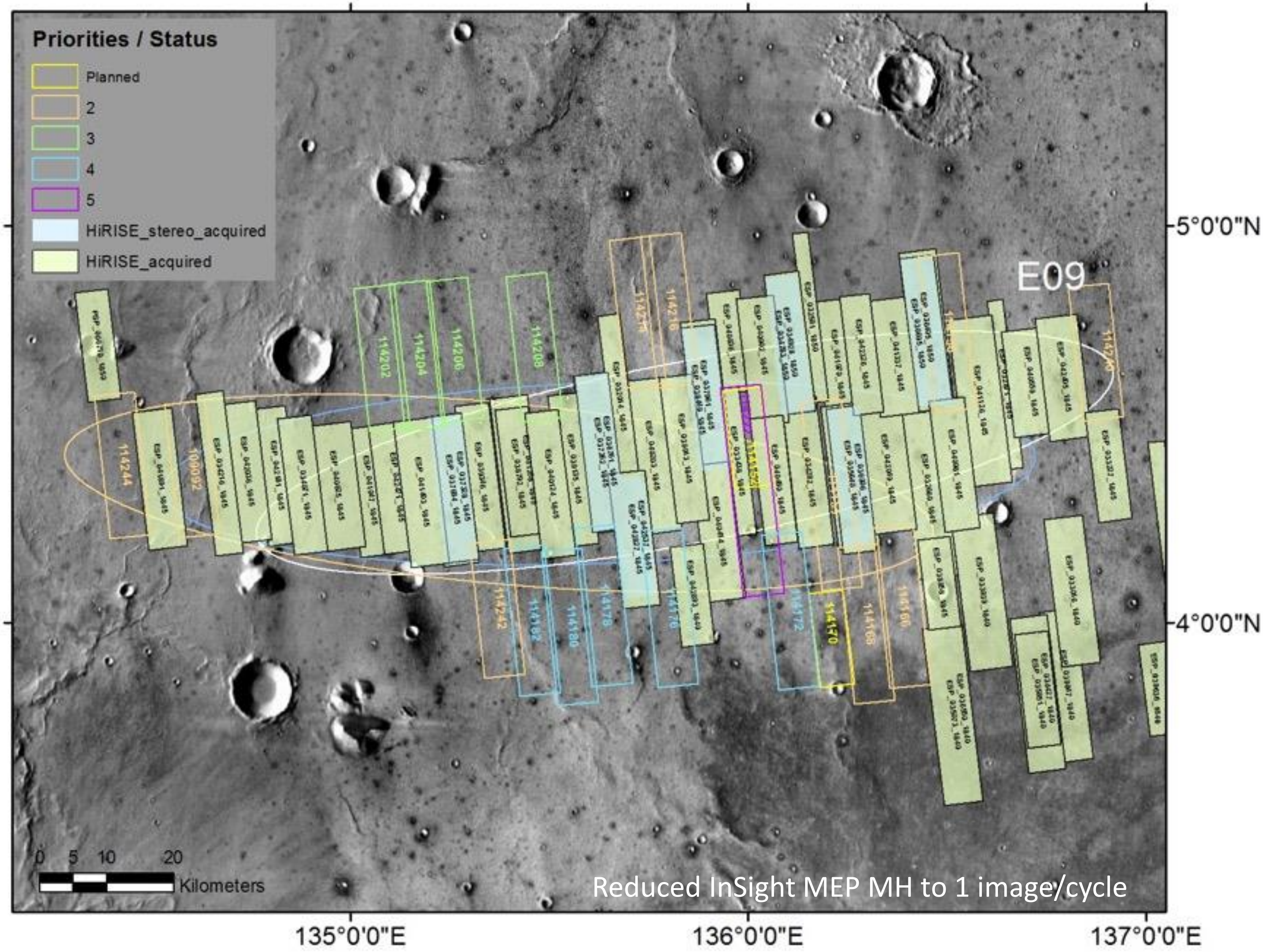


Image Coverage and Requests as of cycle 234 10/15



2018 Re-Planning

- Leak in SEIS Vacuum suspended launch in 2016
- Project Worked Plan for Launch 2018
  - Can only launch to Mars once evert 26 months
- NASA Approved Project for Launch May 2018
- Type 1 Trajectory – Land November 2018
  - Better Opportunity than 2016
  - Less Delta V
  - Lower Arrival Velocity
  - What About Landing Site? – 3 Factors
  - Latitude, Ellipse Size – unlikely to change much
  - Elevation – Determined by Atmosphere Density
    - Varies 25% Seasonally

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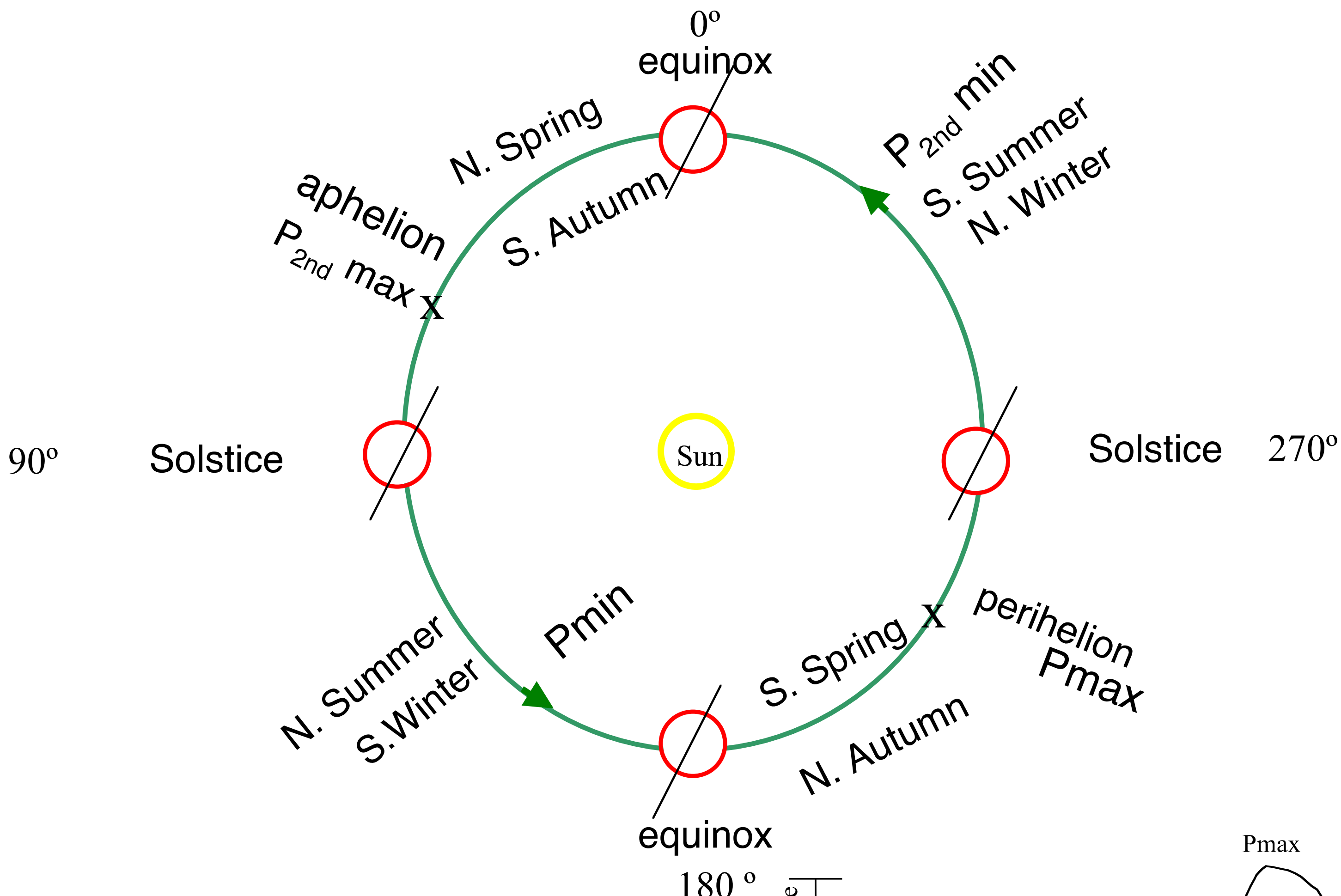
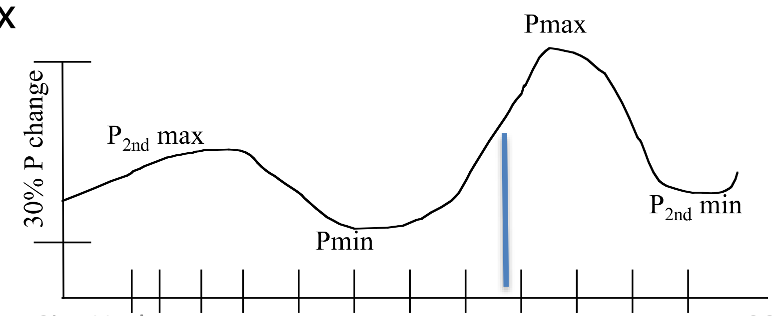
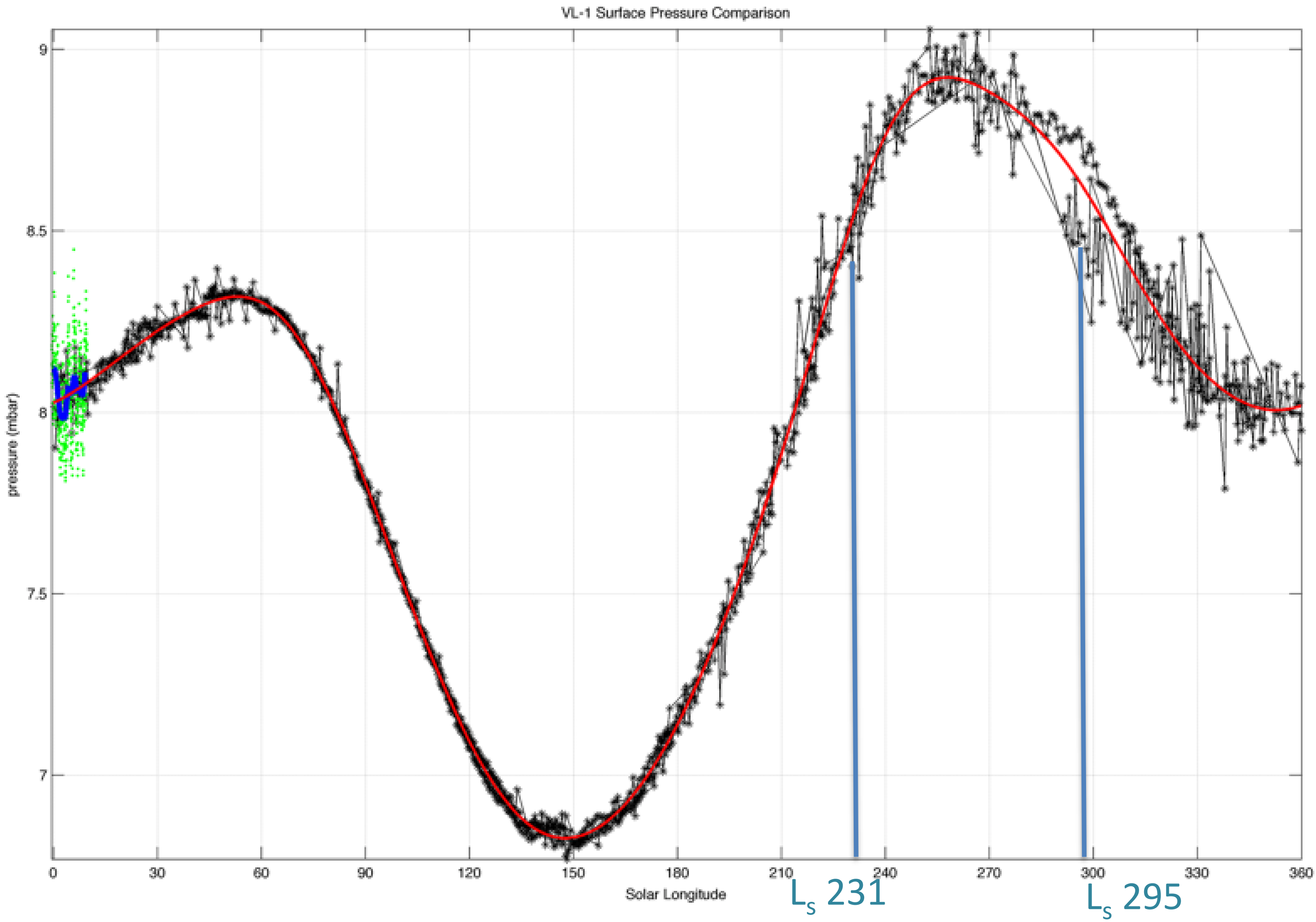
Atmospheric Pressure Cycle



Atmospheric Pressure Cycle on Mars
Seasonal & Orbital Effects



VL1 Surface Atmospheric Pressure



Type 1 Trajectory 2018: Launch May 2018, Arrive November 2018

MRO and DTE Communications on Landing

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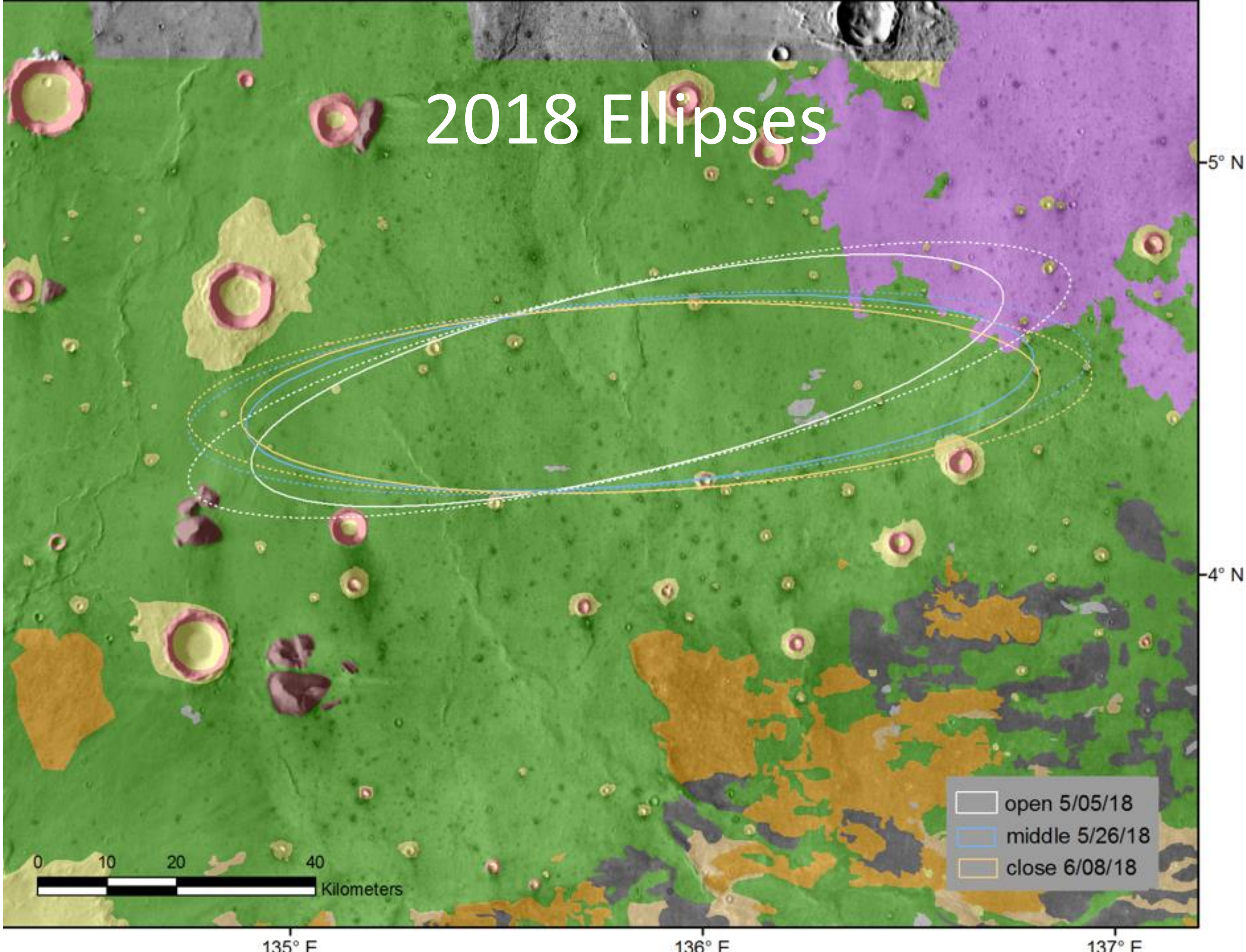
No Other Science Requirements: Just Land Safely

2016 Ellipses

2018 Ellipses



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No Other Science Requirements: Just Land Safely

Thermal Inertia

- **Requirement**
- **Thermal Inertia:** >100−140 J m^{-2} K^{-1} $s^{-1/2}$
  - Avoid surfaces with thick dust that is not loading bearing
  - Prefer ~200 J m^{-2} K^{-1} $s^{-1/2}$ for uncemented or poorly cemented soil
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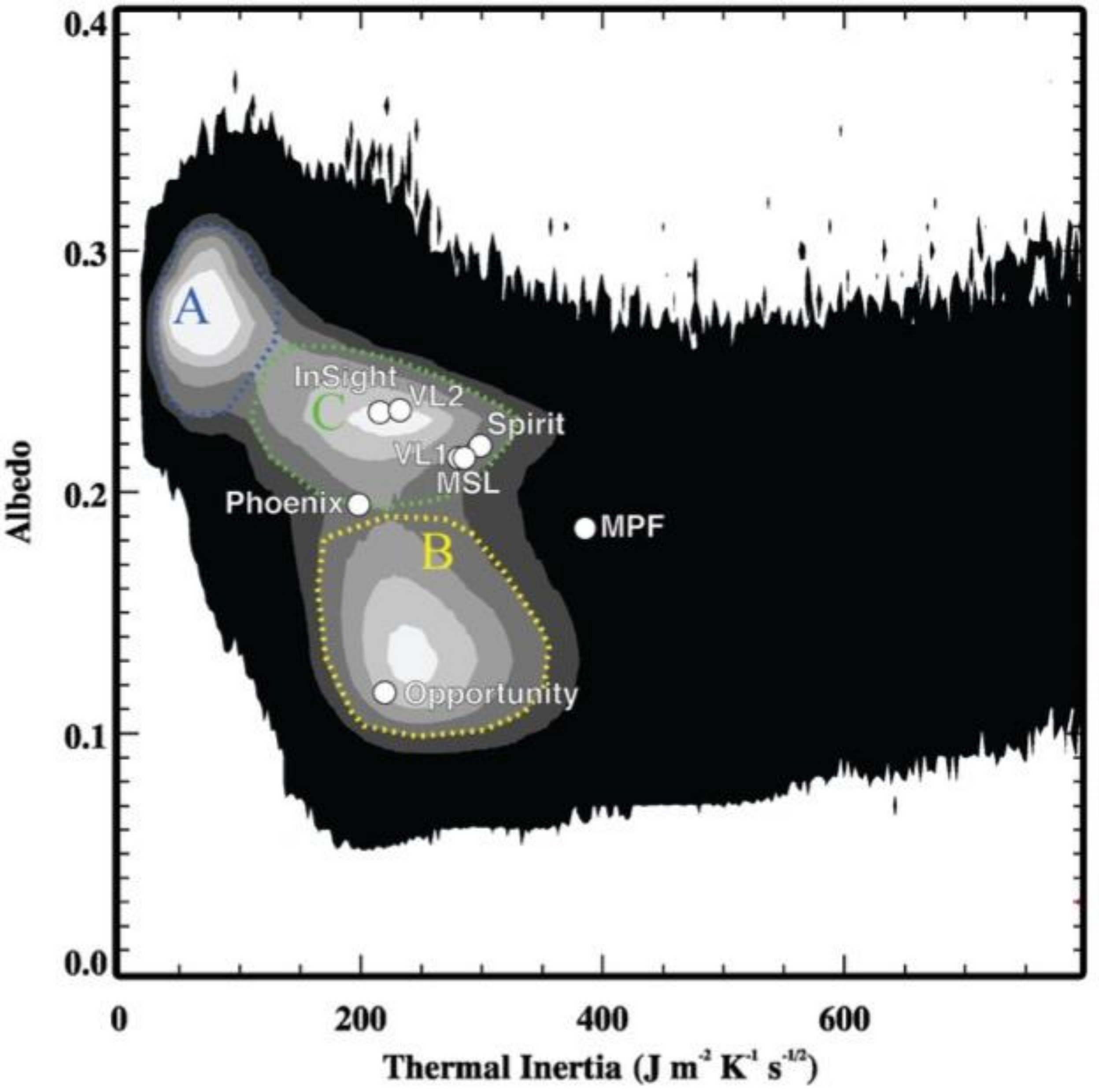
Mars Thermal Inertia versus Albedo



A – Dust:

v. low Thermal Inertia, v. high albedo

B - Dust Free:

v. Low albedo

C – Duricrust:

Moderate Thermal Inertia, Int. albedo

80% of Mars

VL1, 2, Spirit, PHX & MSL in Unit C

MPF similar but higher thermal inertia

Opportunity in Unit B

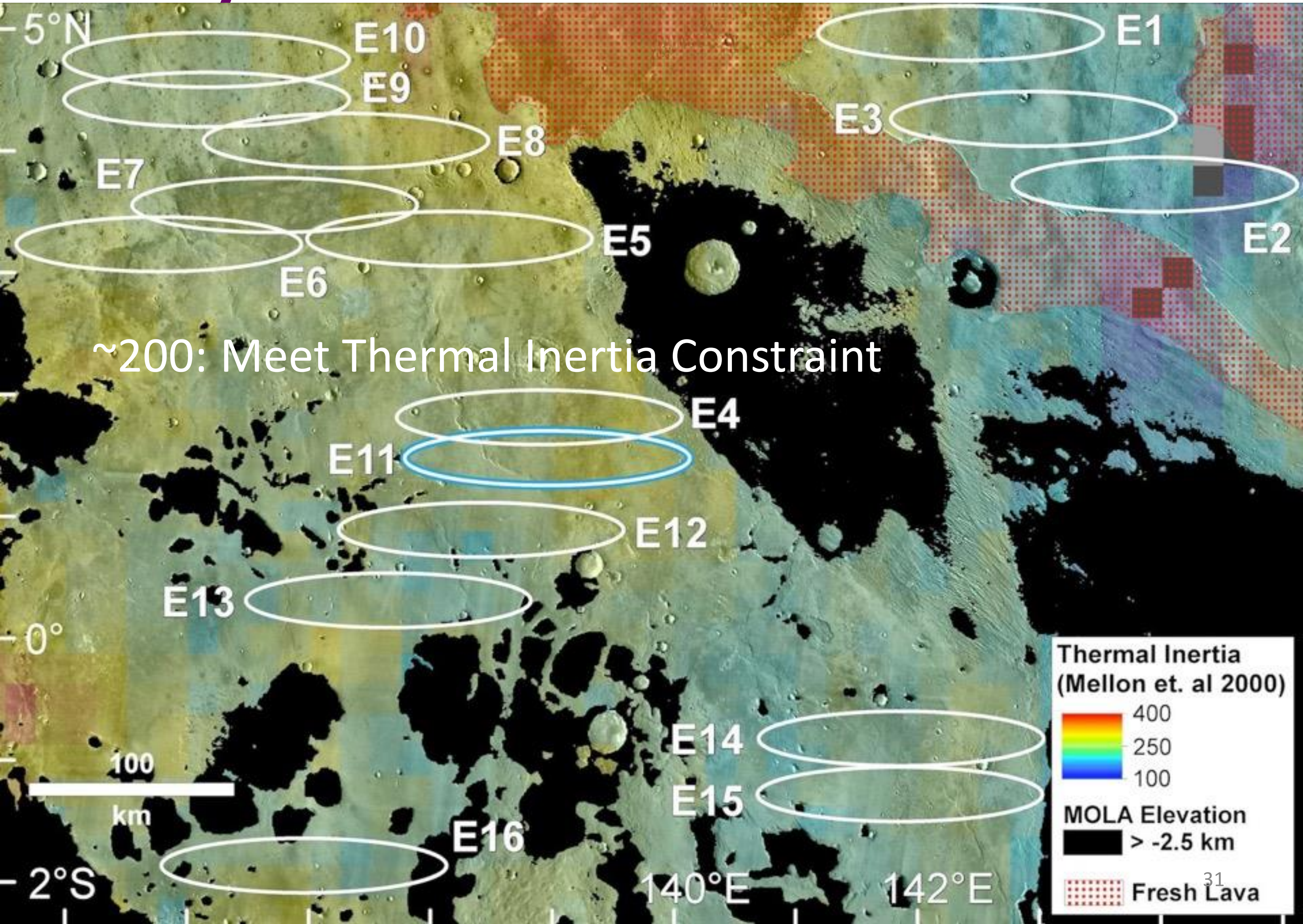
InSight in Unit C

Albedo – as dusty as VL2, SPI

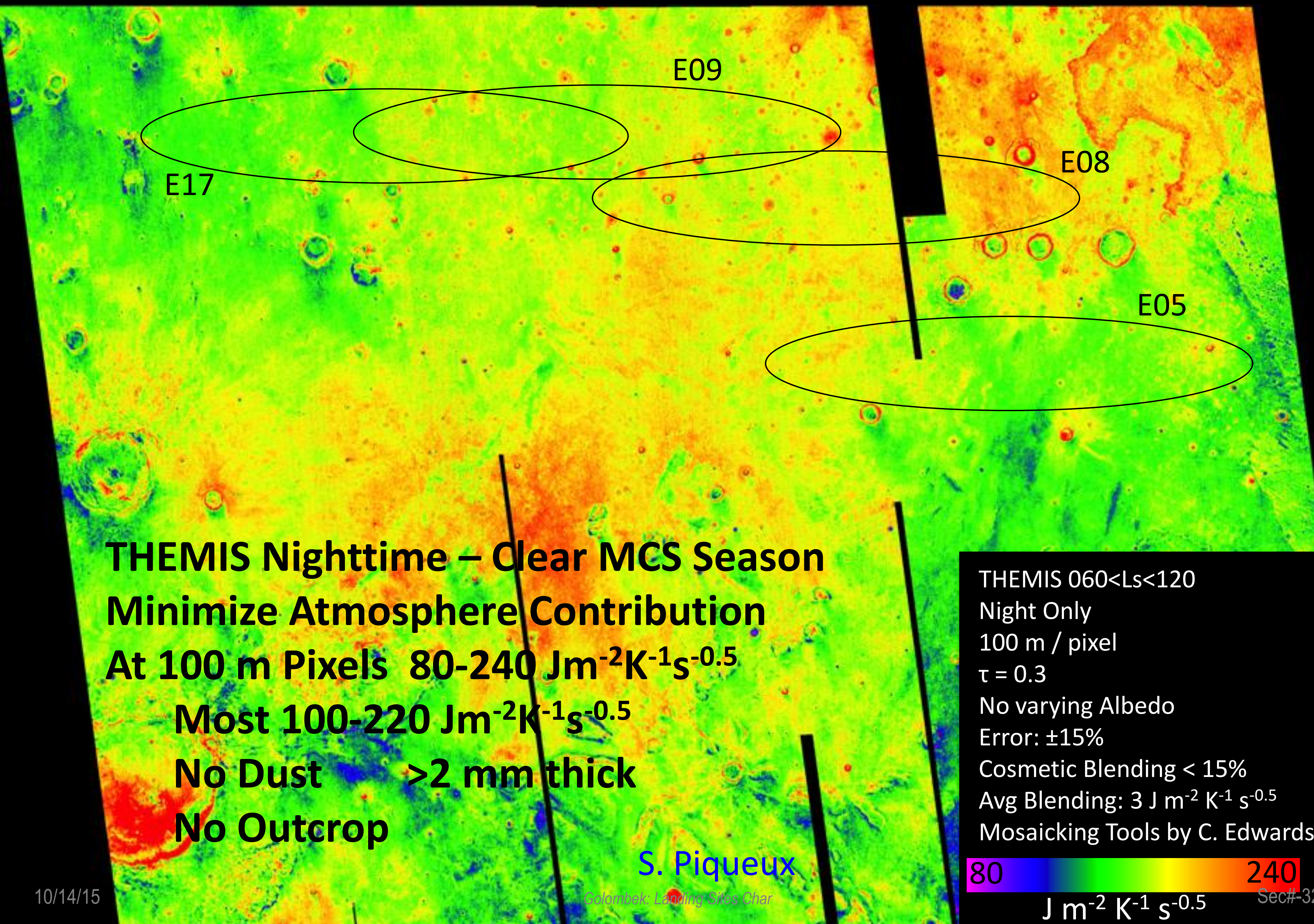
Thermal Inertia – soils like VL2, OPP, PHO, SPI [low cohesion]

Putzig et al.

Elysium Planitia Thermal Inertia



Thermophysical Properties: THEMIS Thermal Inertia

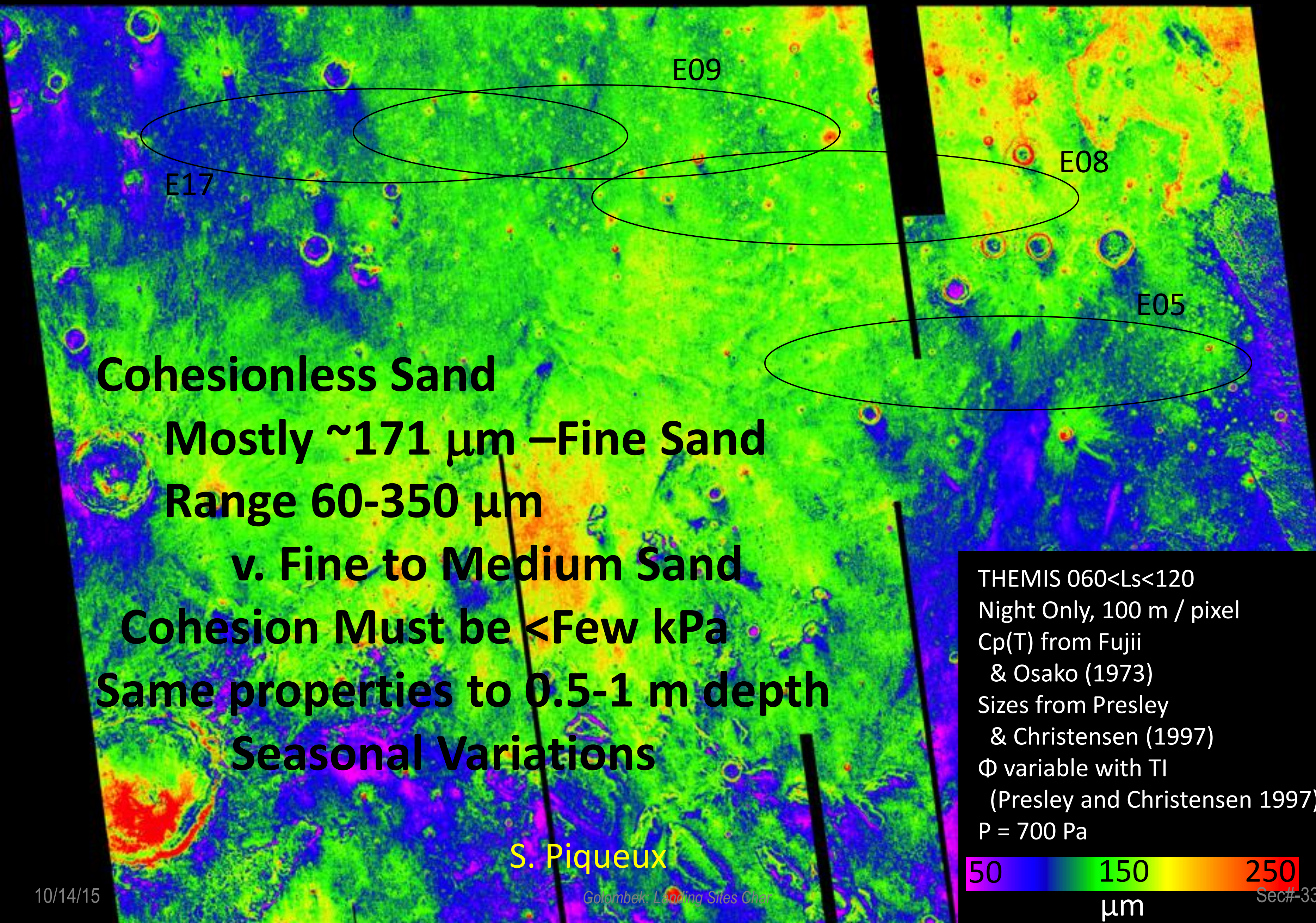


THEMIS Nighttime – Clear MCS Season
Minimize Atmosphere Contribution
At 100 m Pixels 80-240 Jm^{-2}K^{-1}s$^{-0.5}$
- **Most 100-220 Jm^{-2}K^{-1}s$^{-0.5}$**
- **No Dust >2 mm thick**
- **No Outcrop**

THEMIS 060<Ls<120
Night Only
100 m / pixel
τ = 0.3
No varying Albedo
Error: ±15%
Cosmetic Blending < 15%
Avg Blending: 3 J m^{-2} K^{-1} s$^{-0.5}$
Mosaicking Tools by C. Edwards

S. Piqueux

Thermophysical Properties: Grain Sizes



Cohesionless Sand

- **Mostly ~171 µm –Fine Sand**
- **Range 60-350 µm**
  - **v. Fine to Medium Sand**
- **Cohesion Must be <Few kPa**

Same properties to 0.5-1 m depth

Seasonal Variations

THEMIS 060<Ls<120
Night Only, 100 m / pixel
Cp(T) from Fujii & Osako (1973)
Sizes from Presley & Christensen (1997)
Φ variable with TI (Presley and Christensen 1997)
P = 700 Pa

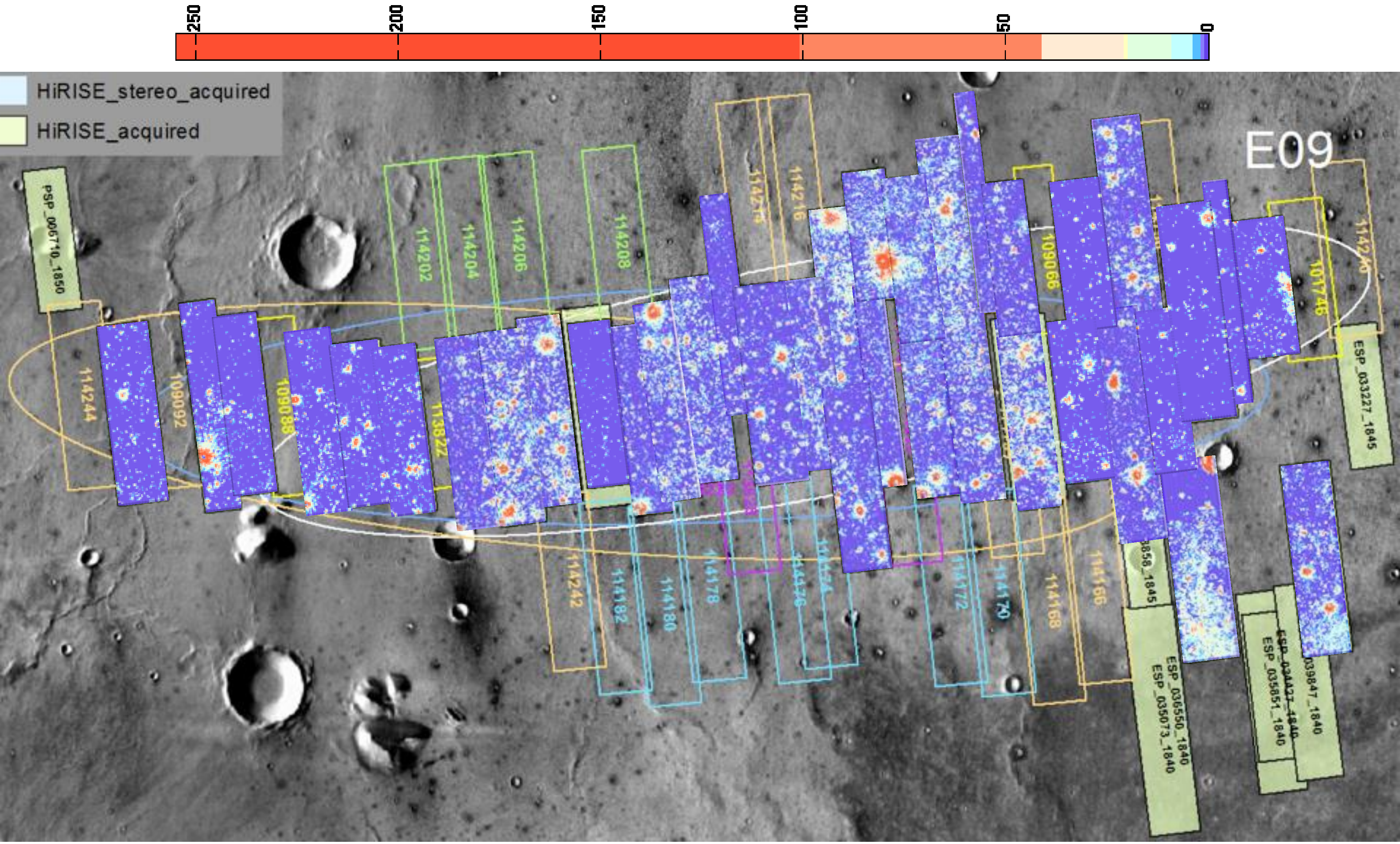
S. Piqueux

Rocks

- **Requirement**
- **Rock Abundance:** <10%
  – 99% Safe Landing and Opening Solar Panels

- **ADAMS Simulations**
  – 2% Failure at 10% Rock Abundance
  – Increases rapidly with higher Rock Abundance

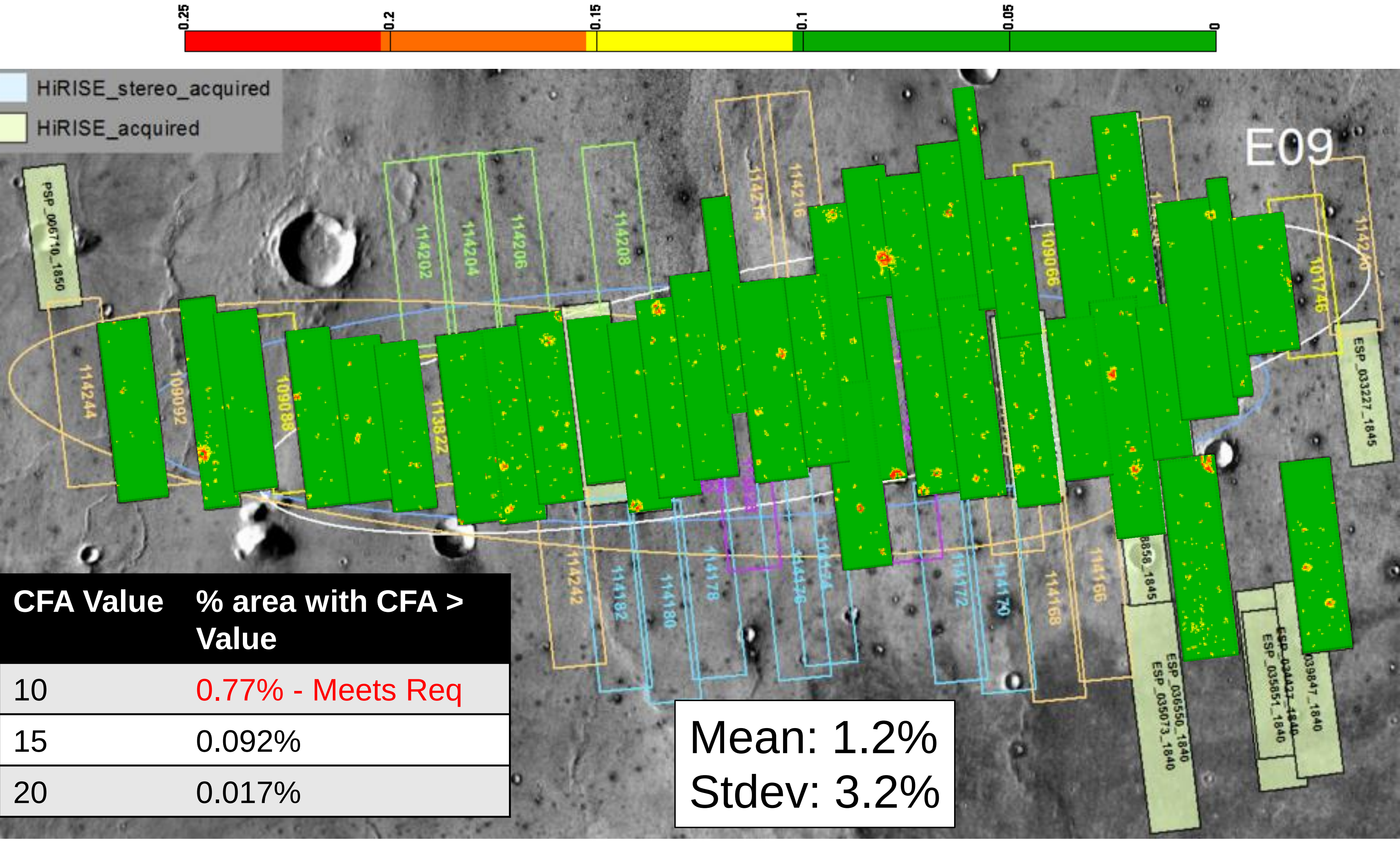
HiRISE Rock Density



Total number of counted rocks in 150m x 150m bins

Huertas

HiRISE Rock CFA - Risk



CFA Value	% area with CFA > Value
10	0.77% - Meets Req
15	0.092%
20	0.017%

Mean: 1.2%
Stdev: 3.2%

CFA <=10% for rocks in 150m x 150m bins

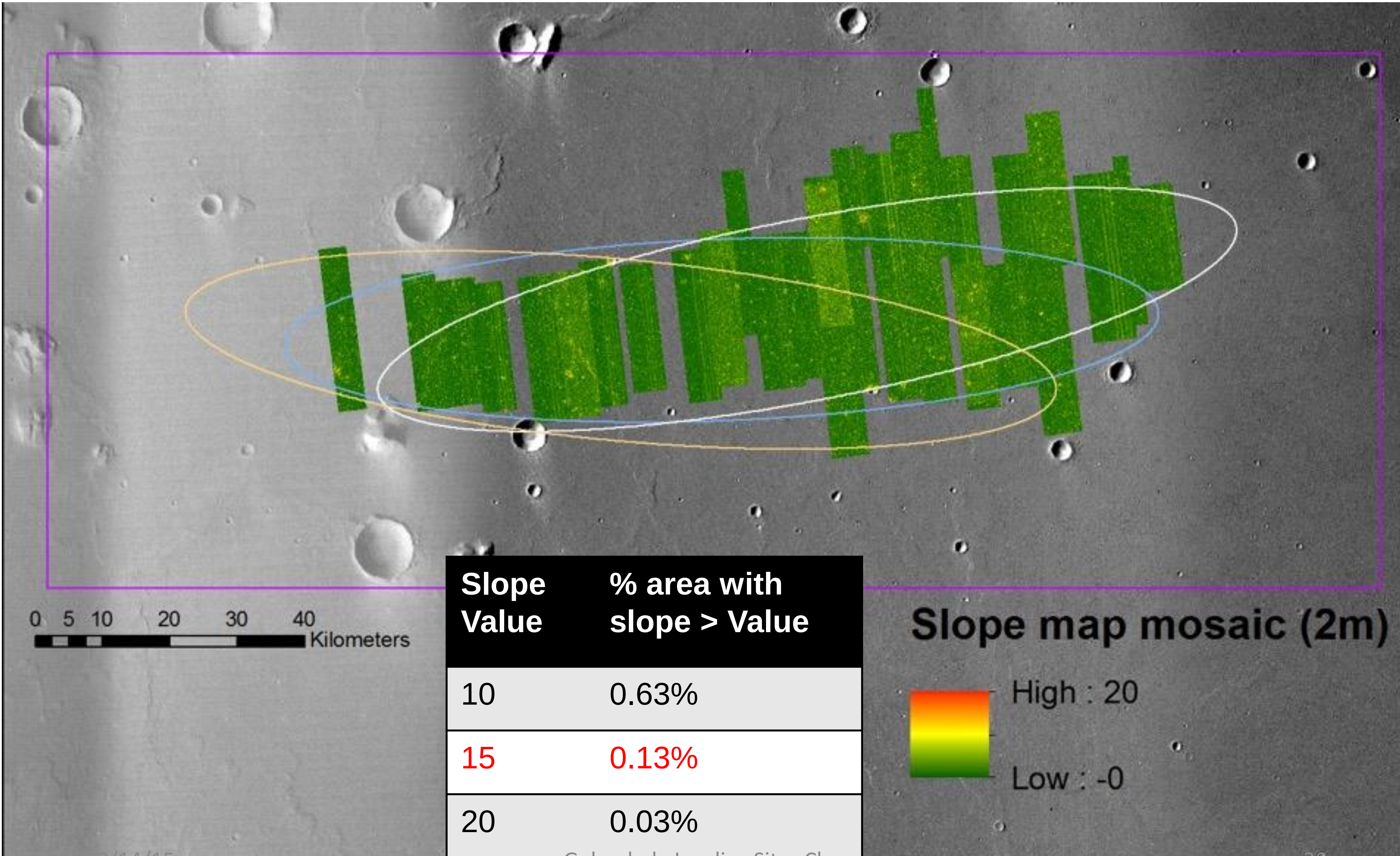
Huertas

Slopes

- Smooth Flat Surface
  - No Large Relief Features
- Slope
  - Slopes <15° for safe touchdown and radar tracking (1−5 m & 84 m)
  - InSight Req. 99% surface has slopes <15°
  - ADAMS – Failure increases gradually above 15°
    - 0% at 15° to ~10% at 20°
- InSight Post Runs
  - Azimuthal Control Worse with Slopes >15°
  - Negatively Impacts RISE
- Payload [SEIS] Fails on Slopes >15°

Slope Map – 2 m

Photoclinometry & DEMs



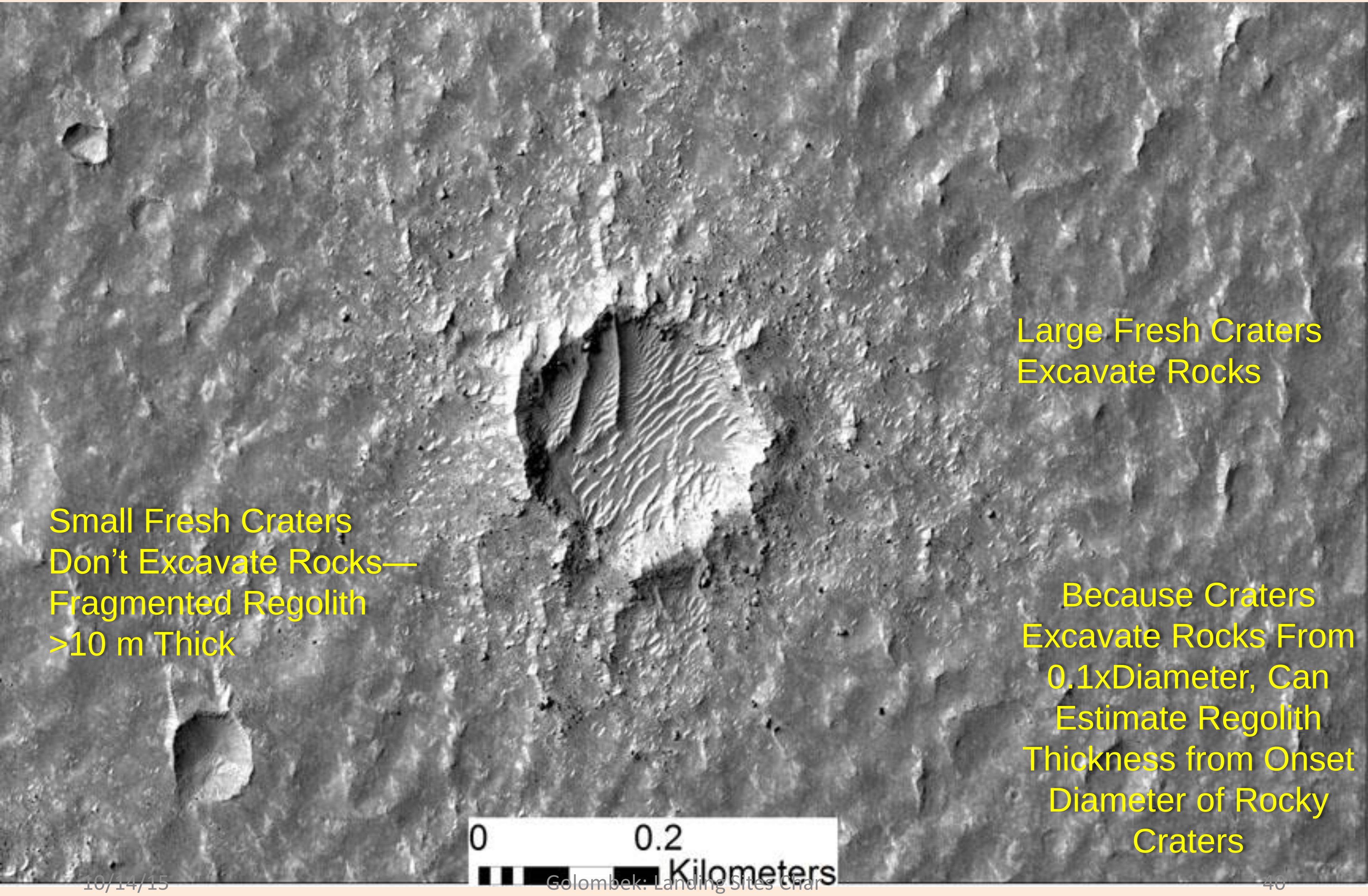
Slope Value	% area with slope > Value
10	0.63%
15	0.13%
20	0.03%

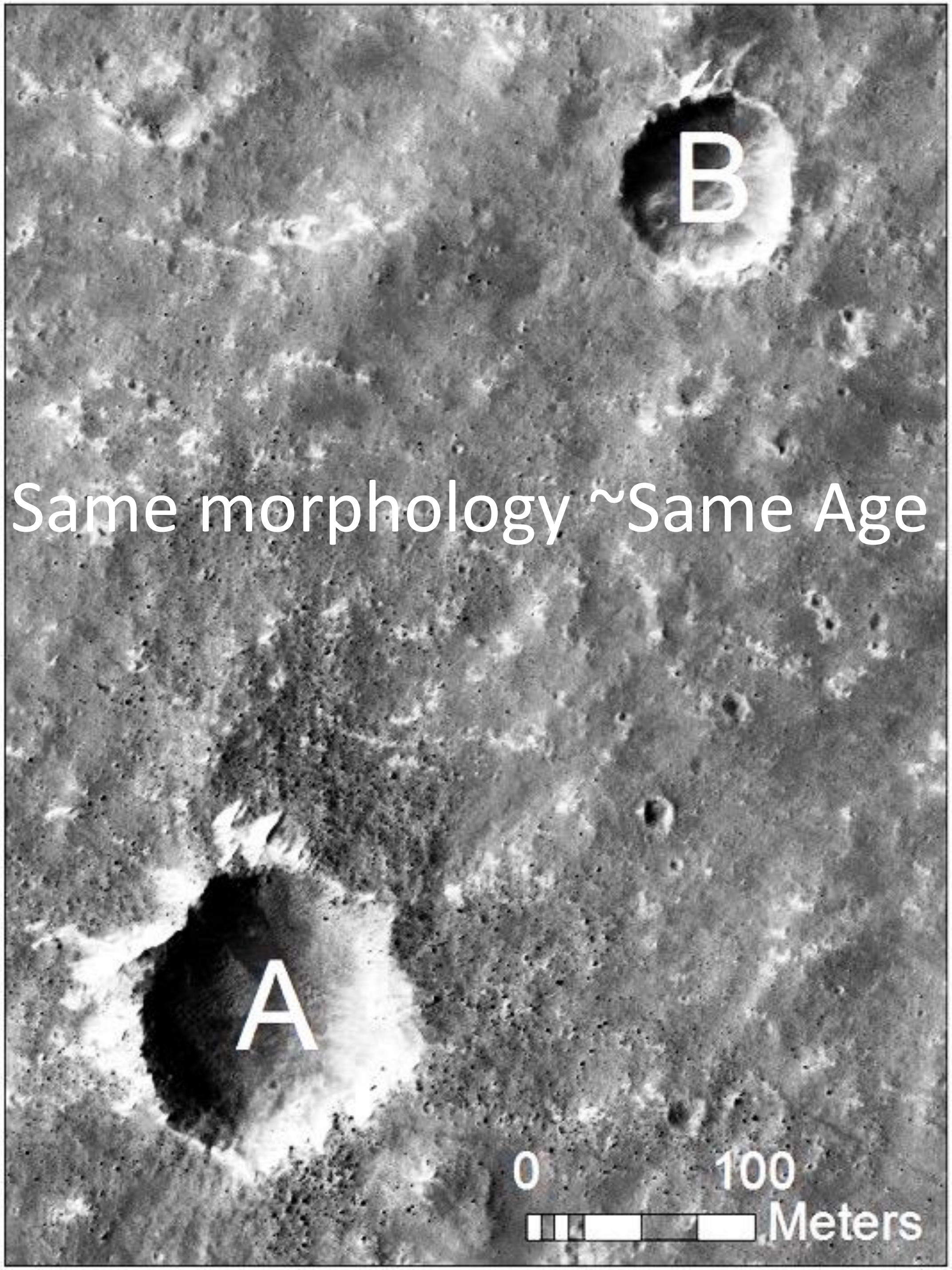
Meets <1% Constraint >15°

Regolith Thickness

- Broken Up Regolith >5 m Thick
  - Penetration of HP3 Mole

Rocky Ejecta Craters

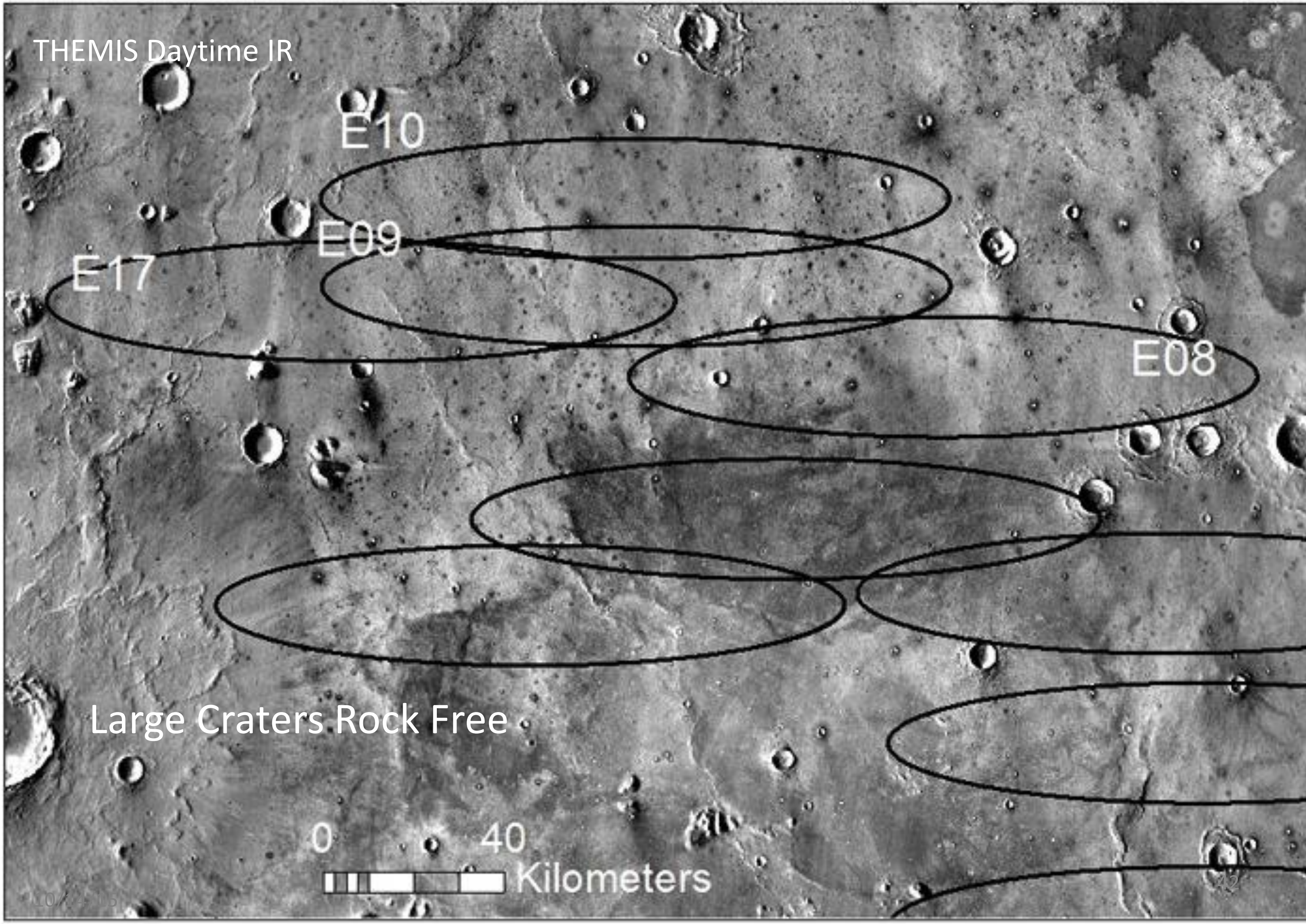




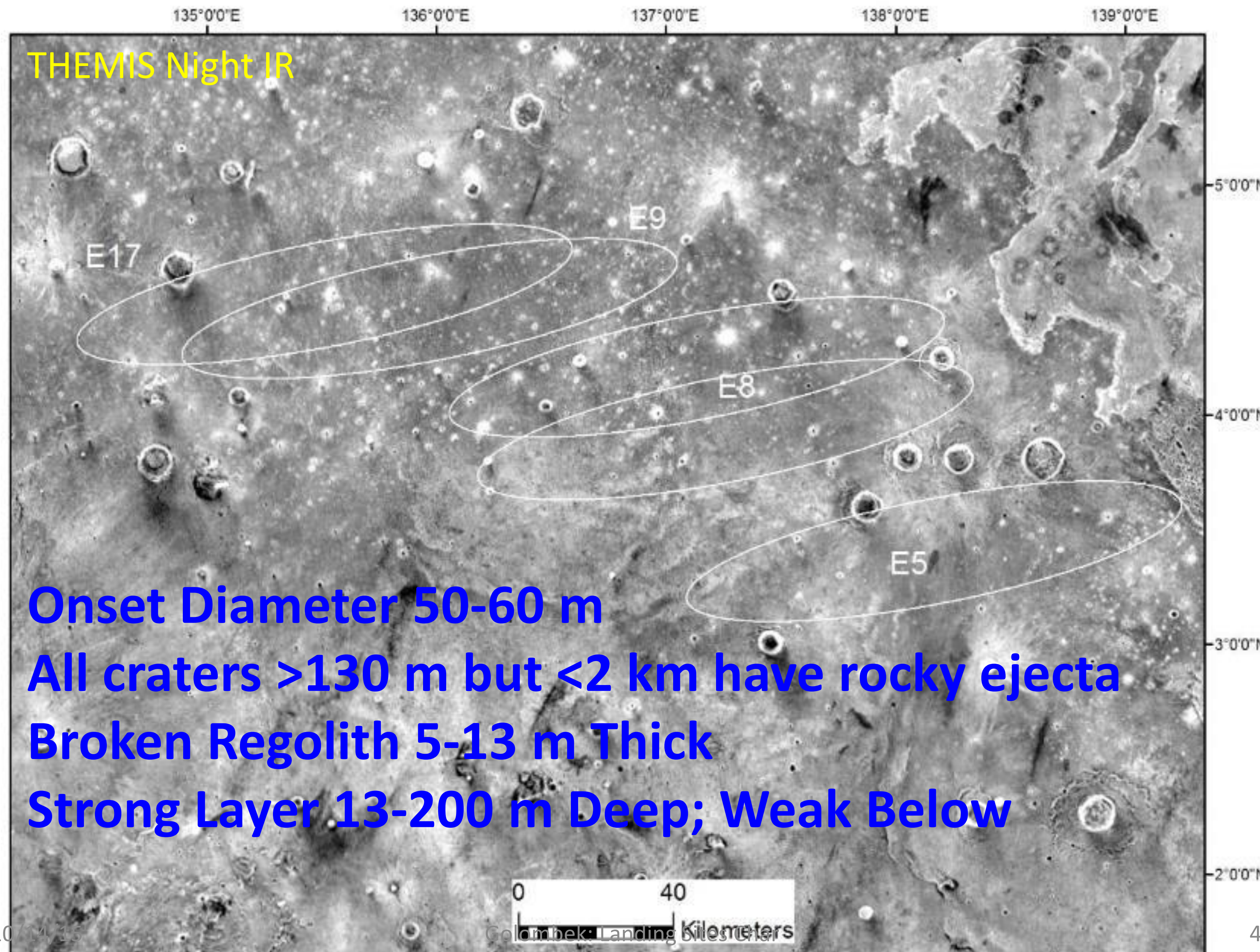
Crater B
Not Rocky Ejecta
75 m Diameter
Ejecta 6 m deep
No rocks, regolith
>6 m thick

Crater A
Rocky Ejecta
112 m Diameter
Rocks excavated
from 8 m, Regolith
<8 m thick

Rocky Ejecta Craters



Rocky Ejecta Craters



Onset Diameter 50-60 m

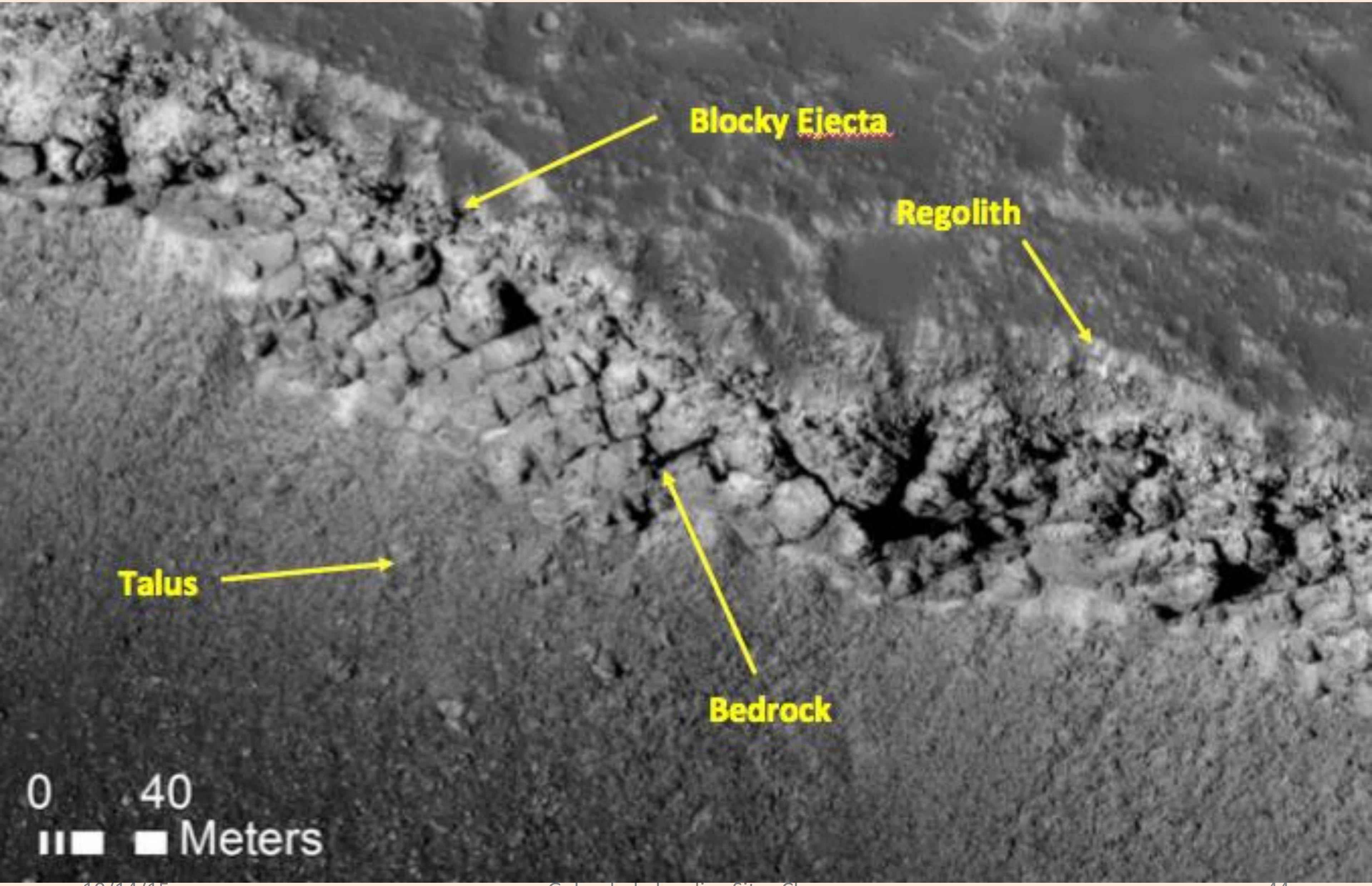
All craters >130 m but <2 km have rocky ejecta

Broken Regolith 5-13 m Thick

Strong Layer 13-200 m Deep; Weak Below

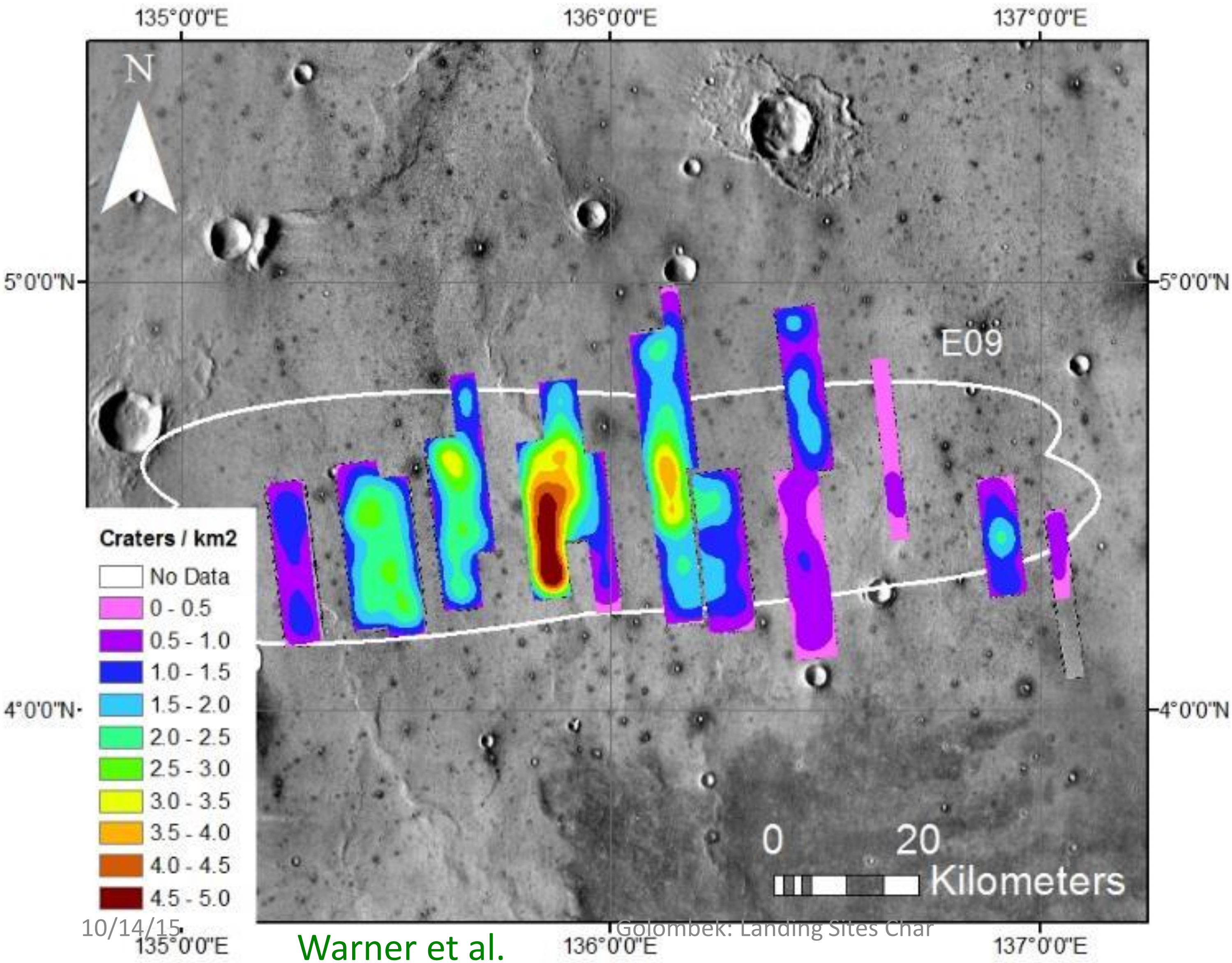
Warner

Cross Section of Regolith



Regolith Thickness Variation?

- Point density map of all RECs including rocky Corinto secondaries.



Warner et al.

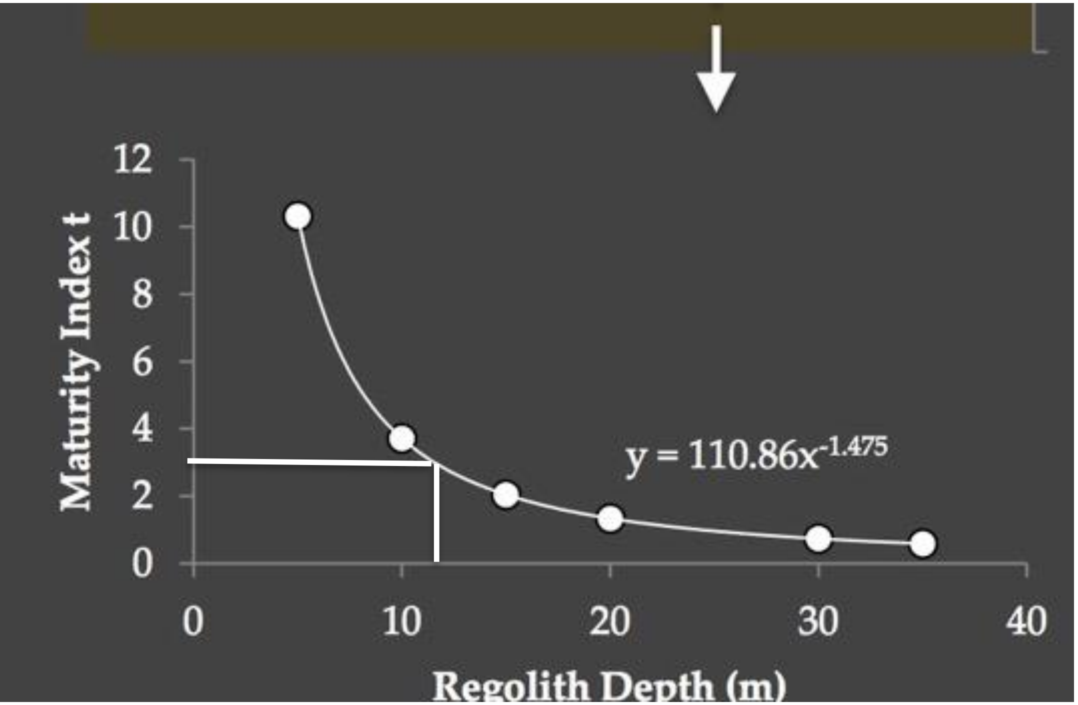
Estimated Thickness of Regolith

Fill in before launch

Tested by Penetration of Mole

Fragmentation Theory

Follows Negative Binomial



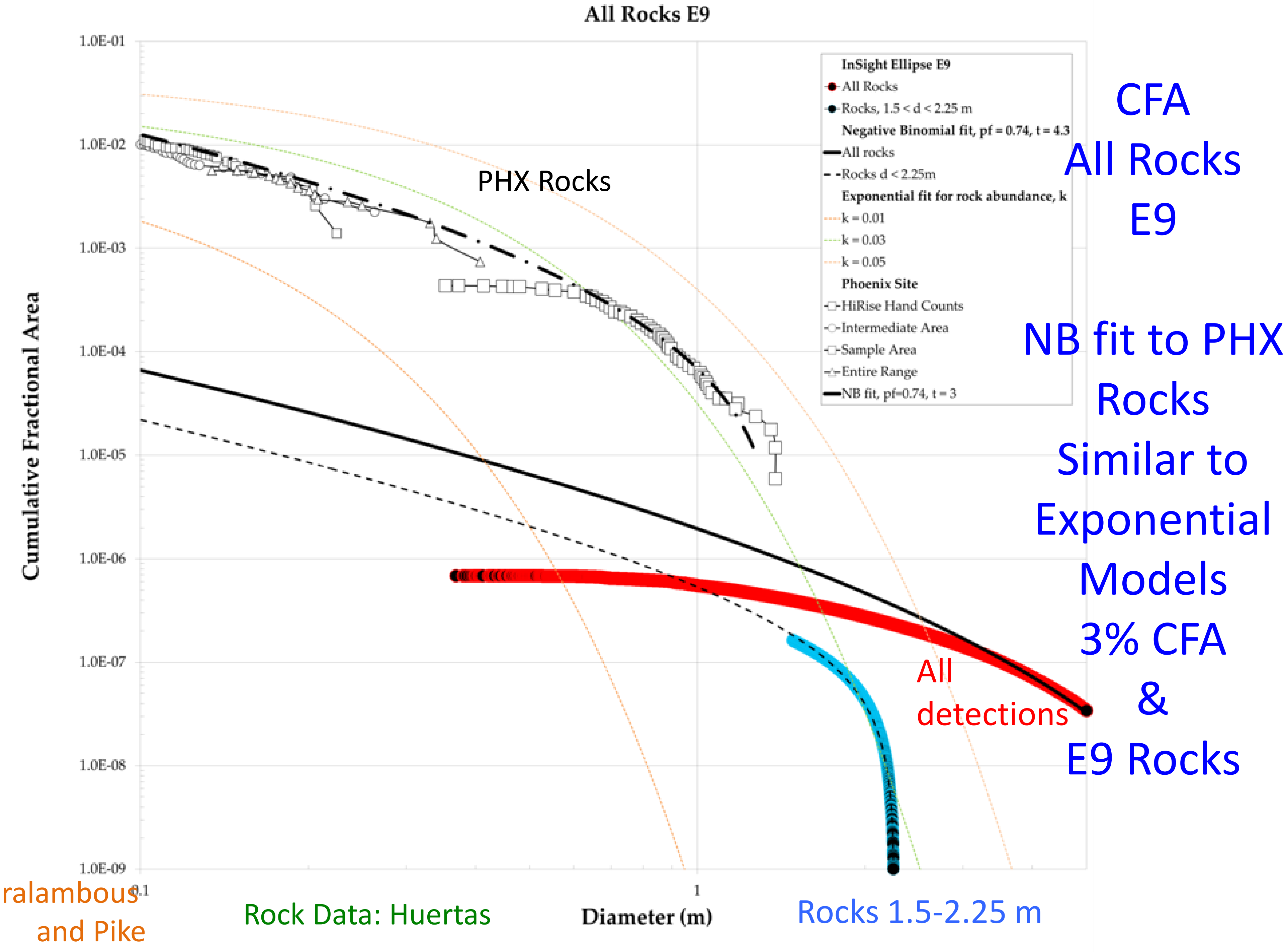
t ~ 3 for 3.5 Ga Hesperian
Cratered Terrain on Mars
Regolith ~10 m Thick

Particle Size Increases with Depth

Mars Cratering over 3.5 Ga

Charalambous and Pike

Model to compare to Regolith Thickness & Rock Distribution



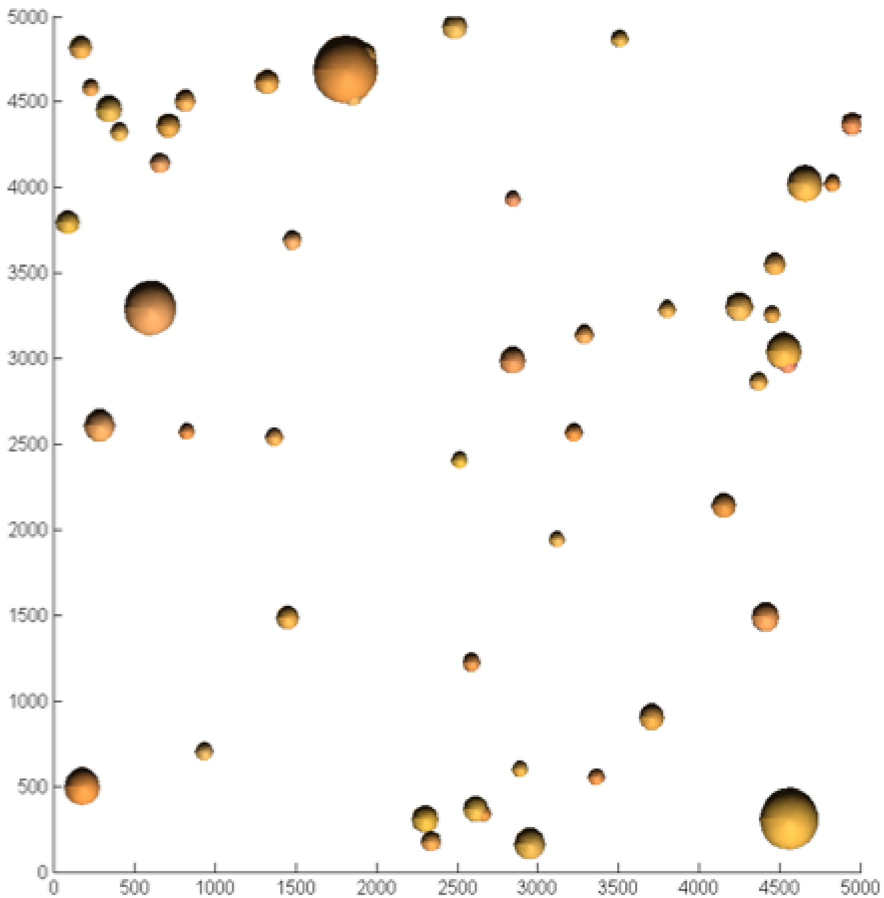
All Rocks E9
Cumulative Fractional Area
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
0.1
1
Diameter (m)
InSight Ellipse E9
All Rocks
Rocks, 1.5 < d < 2.25 m
Negative Binomial fit, pf = 0.74, t = 4.3
All rocks
Rocks d < 2.25m
Exponential fit for rock abundance, k
k = 0.01
k = 0.03
k = 0.05
Phoenix Site
HiRise Hand Counts
Intermediate Area
Sample Area
Entire Range
NB fit, pf=0.74, t = 3
PHX Rocks
All detections
CFA
All Rocks
E9
NB fit to PHX
Rocks
Similar to
Exponential
Models
3% CFA
&
E9 Rocks
ralambous
and Pike
Rock Data: Huertas
Rocks 1.5-2.25 m

NB Monte Carlo Simulations

Rocks >10 cm

5 m Cube

All Particles



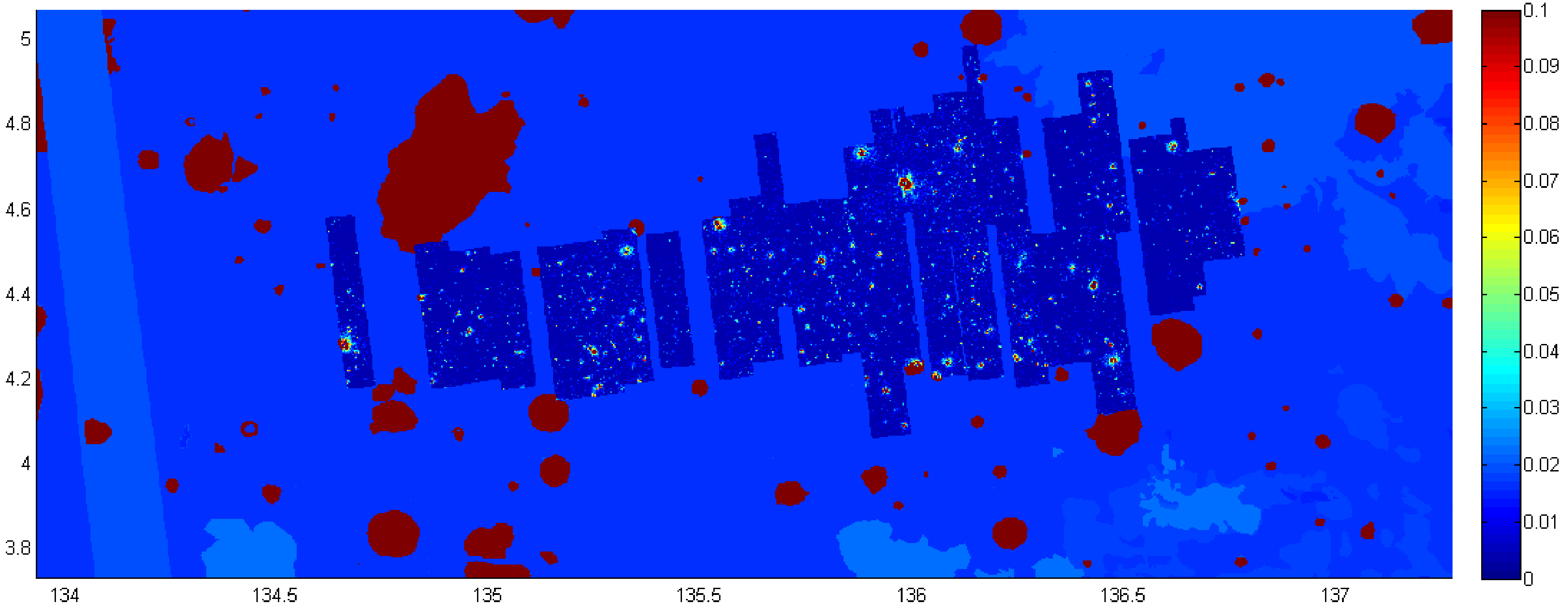
Charalambous and Pike

>90% Mole Penetrate 5 m

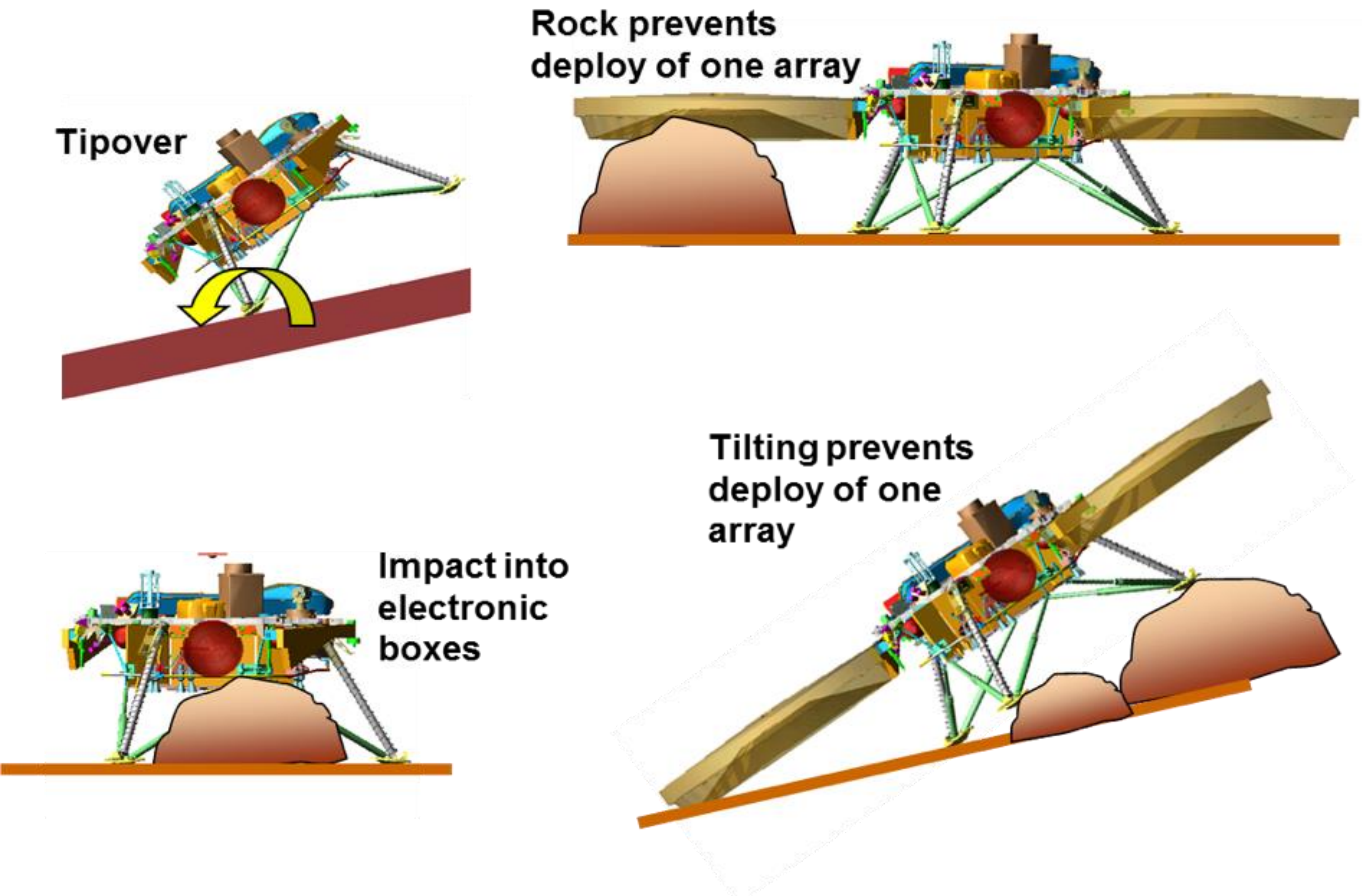
Equilibrium between Impact and Redistribution of Fines

Modeled and Tested by Penetration of Mole

Hazard Map (HiRISE with Terrain Map in Background)

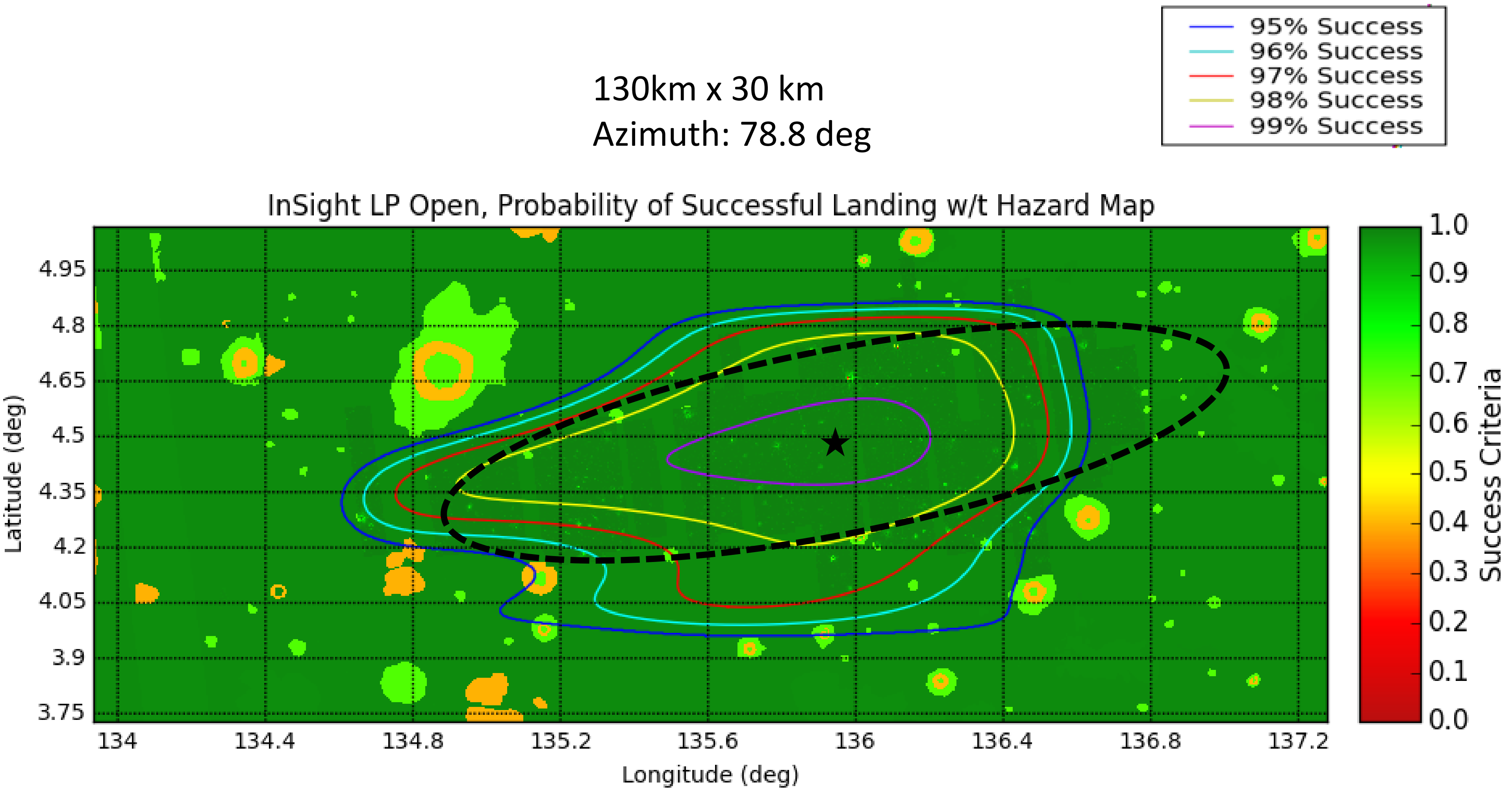


Risk from Rocks & Slopes



InSight Probability Success

130km x 30 km
Azimuth: 78.8 deg



Maximum Success Probability: 99.20 %
Optimum Ellipse Center
Lat: 4.475 deg N
Lon: 135.917 deg E

Landing Site Paper – Golombek et al.

- Published Space Science Reviews, 2017 Journal, v. 211
- p. 5-95 - 90 Pages
- 9 tables; 43 Figures
- Table of Contents

- DOI 10.1007/s11214-016-0321-9

Published Characterization Papers

- Fergason, R., Kirk, R. L., Cushing, G., Galuzska, D. M., Golombek, M. P., Hare, T. M., Howington-Kraus, E., Kipp, D. M., and Redding, B. L., 2017, Analysis of local slopes at the InSight landing site on Mars: Space Science Reviews, v. 211, p. 109-133, DOI 10.1007/s11214-016-0292-x.
- Beyer, R., 2017, Meter-Scale Slopes of Candidate InSight Landing Sites from Point Photoclinometry, Space Science Reviews, v. 211, p. 97-107, DOI 10.1007/s11214-016-0287-7.
- Putzig, N. E., Morgan, G. A., Campbell, B. A., Grima, C., Smith, I. B., Phillips, R. J., and Golombek, M. P., 2017, Radar-Derived Properties of the InSight Landing Site in Western Elysium Planitia on Mars: Space Science Reviews, v. 211, p. 135-146, DOI 10.1007/s11214-016-0322-8.
- Warner, N. H., Golombek, M. P., Sweeney, J., Fergason, R., Kirk, R., and Schwartz, C., 2017, Near surface stratigraphy and regolith production in southwestern Elysium Planitia, Mars: Implications for Hesperian-Amazonian terrains and the InSight lander mission: Space Science Reviews, v. 211, p. 147-190, DOI 10.1007/s11214-017-0352-x.
- Bloom, C., Golombek, M., Warner, N., and Wigton, N., 2014, Size frequency distribution and ejection velocity of Corinto crater secondaries in Elysium Planitia (expanded abstract) : Eighth International Conference on Mars, Pasadena, CA, July 14-18, 2014, Abstract #1289, Lunar and Planetary Institute, Houston.
- Sweeney, J., Warner, N. H., Golombek, M. P., Kirk, R., Fergason, R. L., and Pivarunas, A., 2016, Crater degradation and surface erosion rates at the InSight landing site, western Elysium Planitia, Mars (expanded abstract): 47th Lunar and Planetary Science, Abstract #1576, Lunar and Planetary Institute, Houston.
- Hundal, C. B., Golombek, M. P., and Daubar, I. J., 2017, Chronology of fresh rayed craters in Elysium Planitia, Mars: (expanded abstract): 48th Lunar and Planetary Science, Abstract #1726, Lunar and Planetary Institute, Houston.