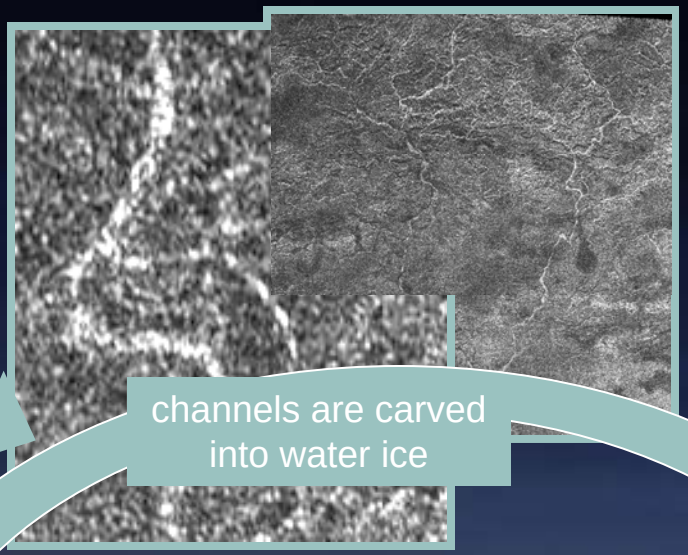
The lakes and seas of Titan: Observations from Cassini RADAR

Karl L. Mitchell
and the Cassini Radar Team

Cassini RADAR Observations: Titan's Hydrocarbon Cycle

methane rain (d ~ cm) falls with hydrocarbon debris (d ~ microns)



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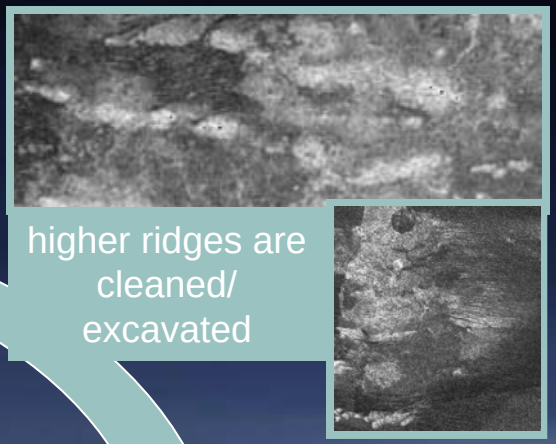

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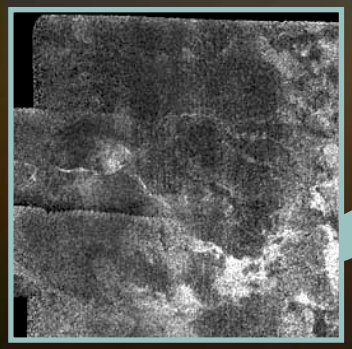
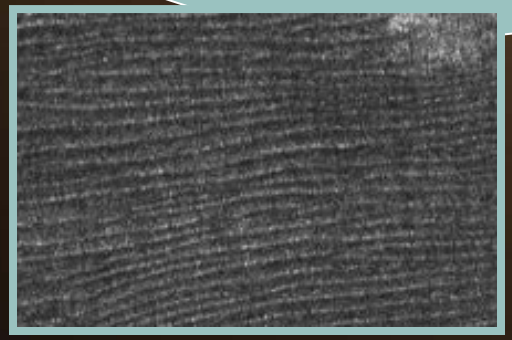


Methane replenished from surface/subsurface via ammonia-water cryovolcanism

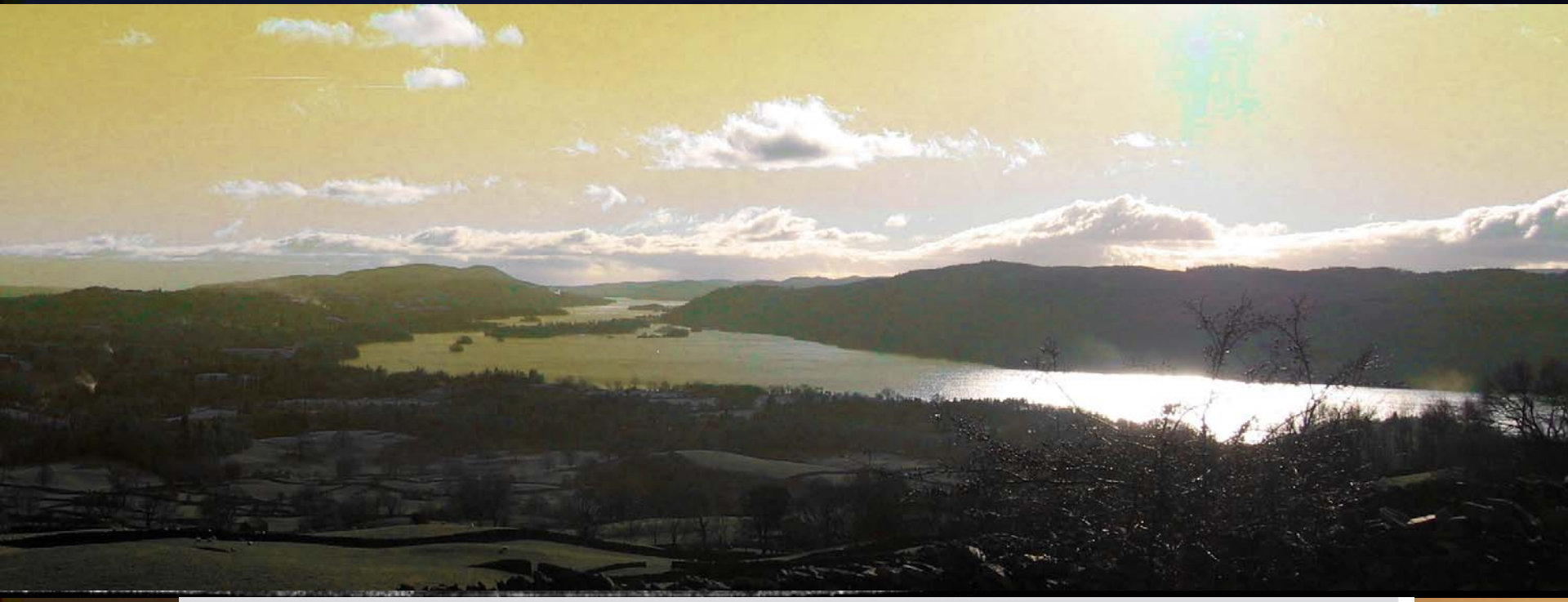


. . . debris also somehow aggregates into ~ 200 μm particles, supplying material from which dunes form

Standing bodies of liquids?

Courtesy S. Wall

Radar team discovers the Lake District



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LETTERS

The lakes of Titan

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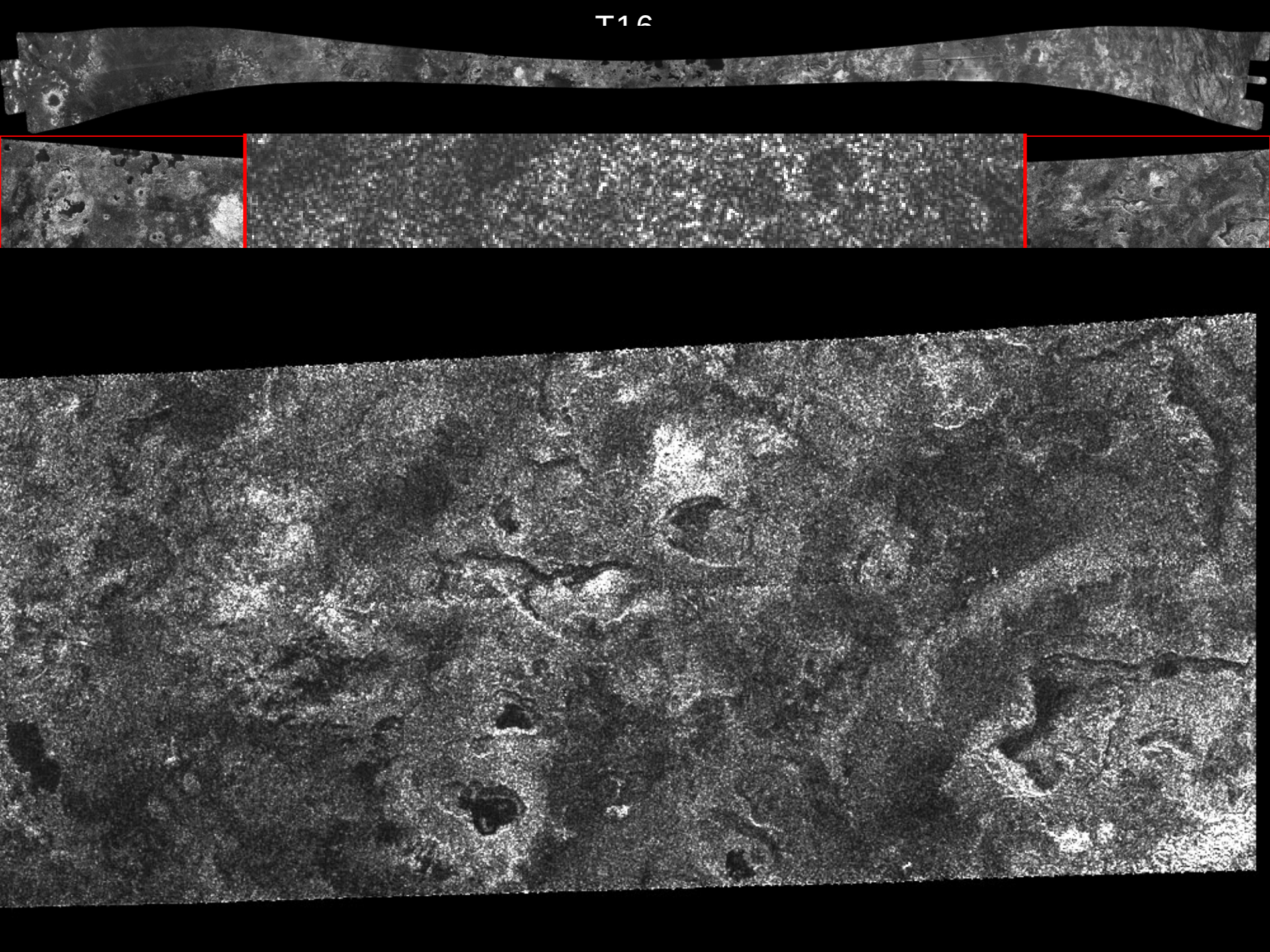
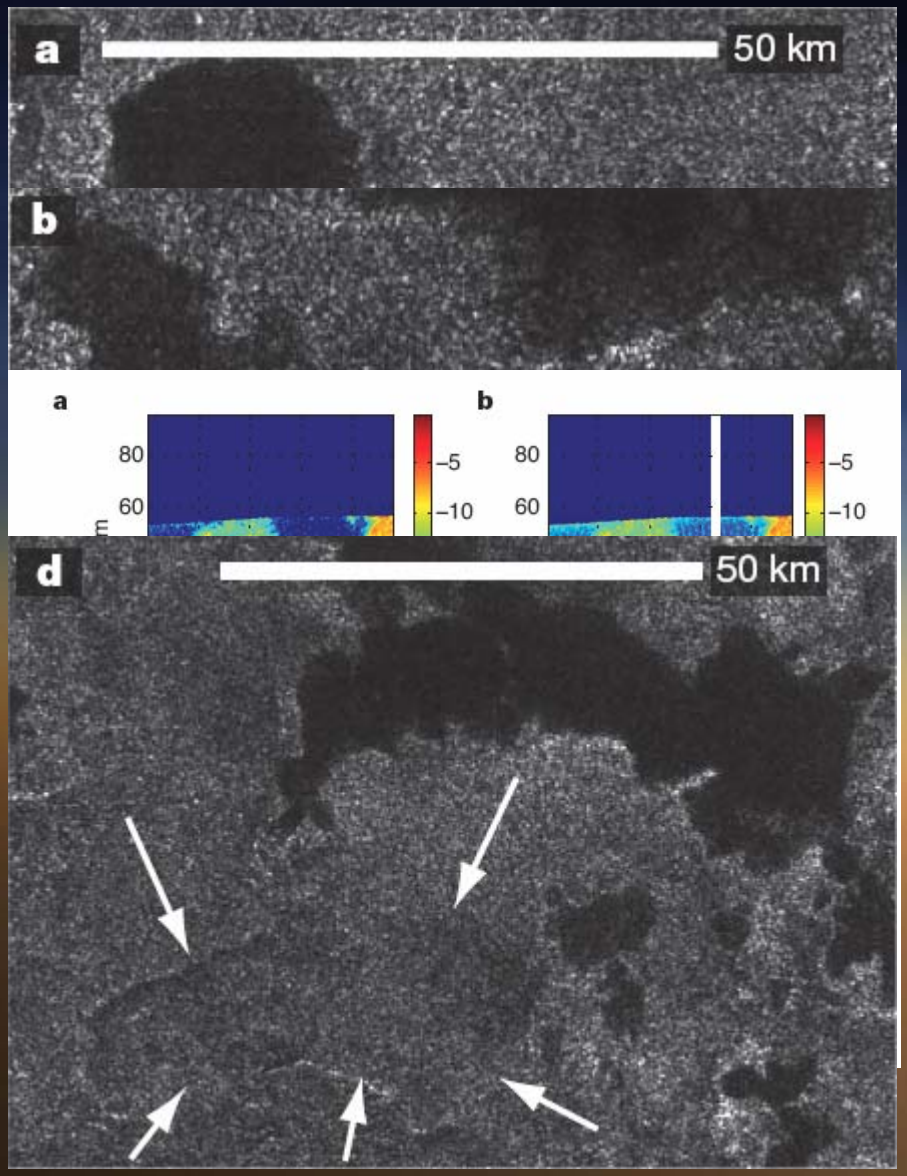

T16

Are these active liquid lakes?

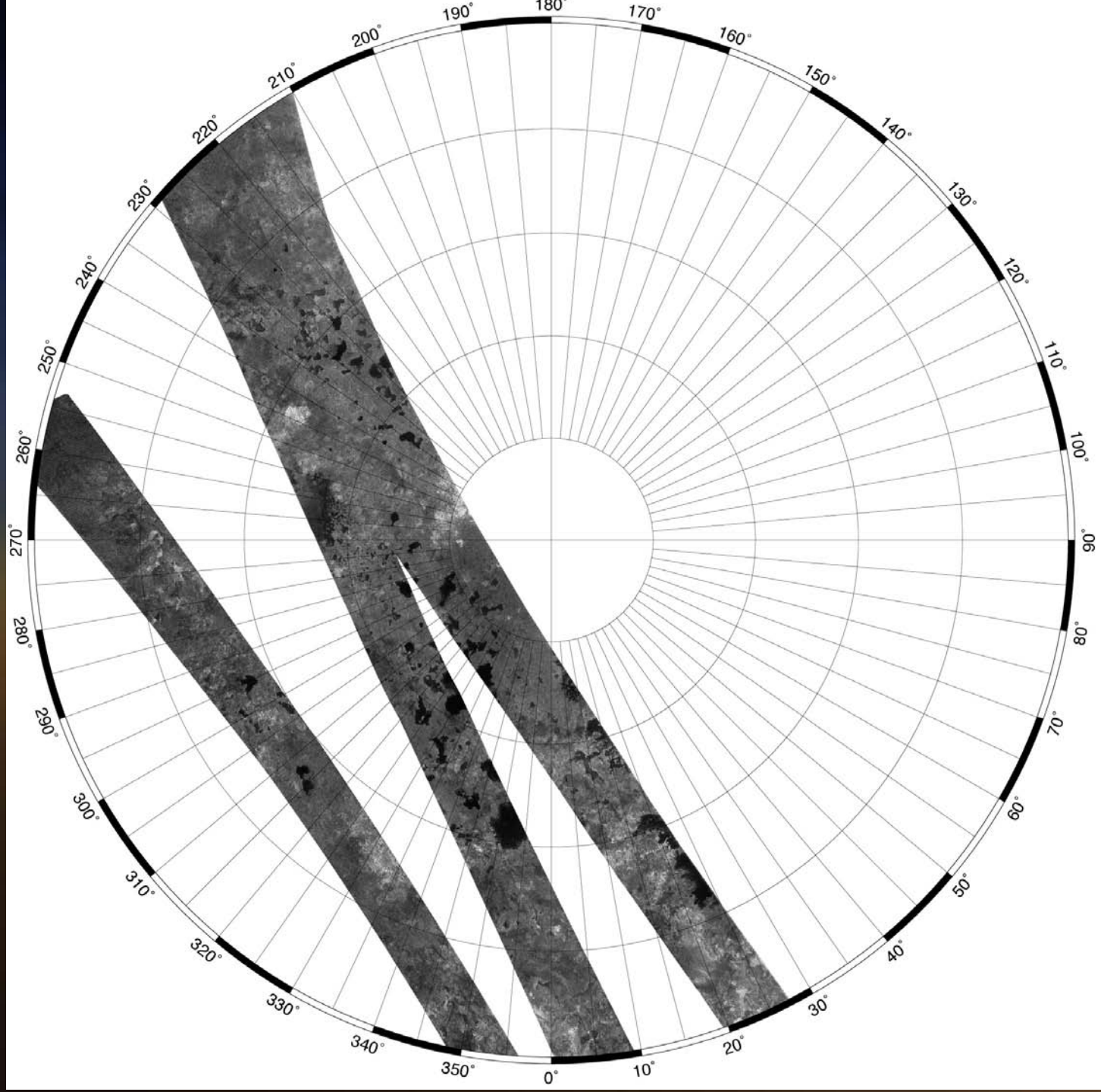
- Dark channel-fed lakes[a,b]
- Shoreline classes:
  - Steep margins: seepage or methanifer
  - Diffuse scalloped margins, decrease backscatter towards lake centre: drainage basins
- Extremely low microwave reflectivity, but no aeolian deposits?[c]
- Consistency with predictions for present-day conditions
- Dichotomy of bright and dark lakes[d]. Playas? Karst-like?
- No “smoking gun”



Next fly-bys

Post-T16

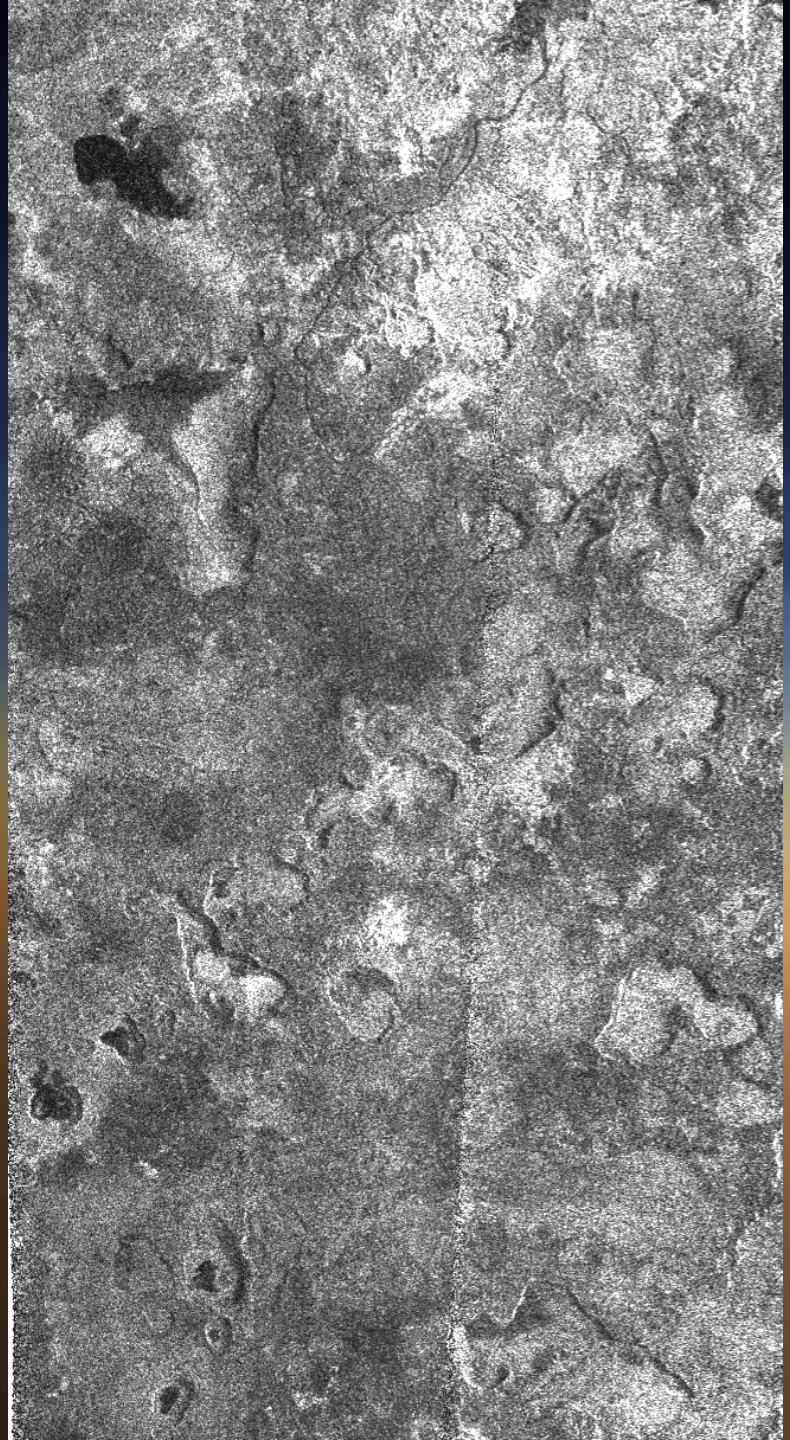
- T18 and T19
- Mostly more of the same
- Lakes have different characteristics in different areas
  - Latitude dependent
  - Clustering



Post-T16

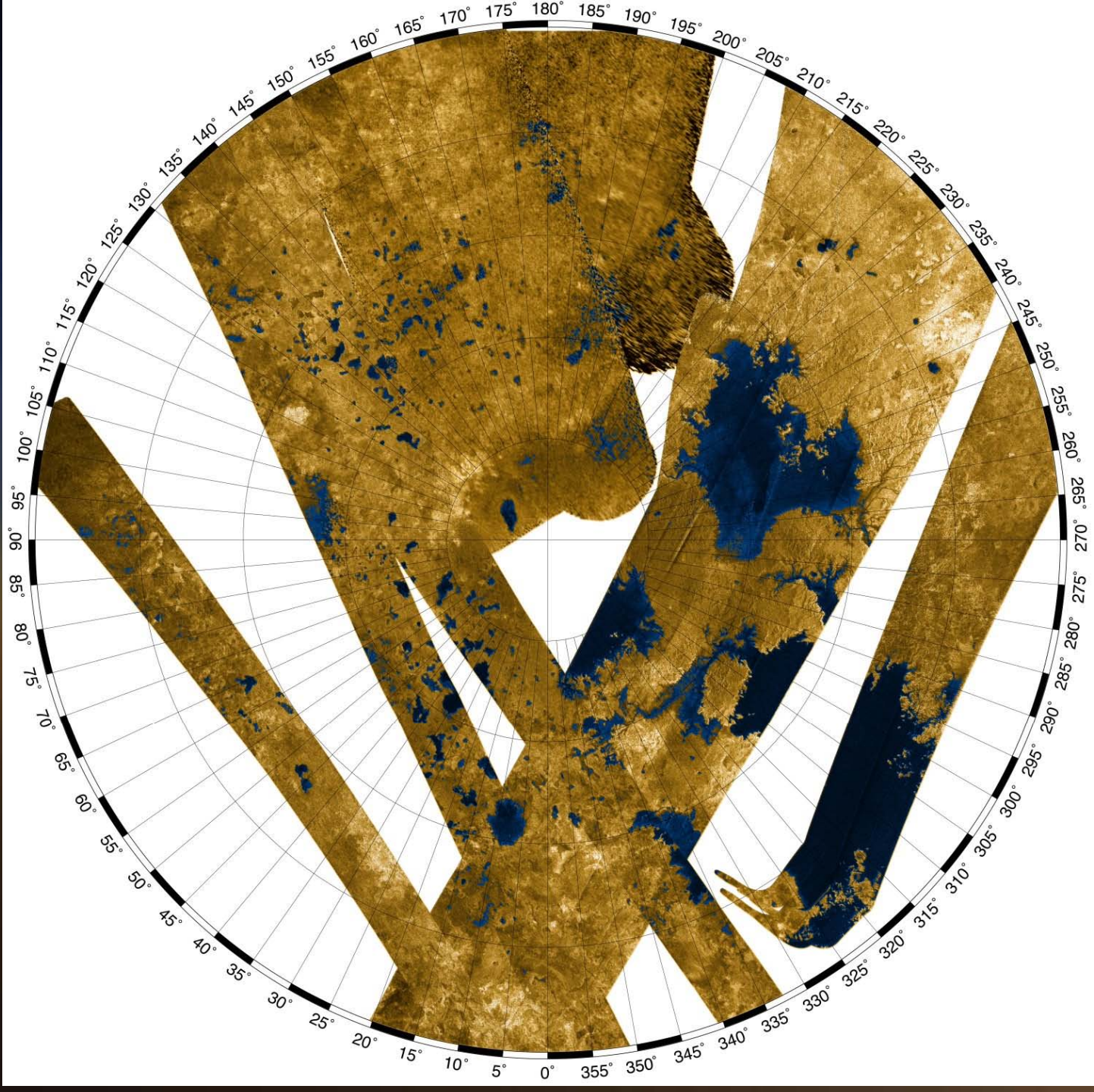
- T19 revealed one more morphology: larger lakes, rugged coastlines, like Lake Powell or Scandinavian fjords
- Growing evidence that we are seeing through liquids, but also consistent with drainage channels on solids
- Areas of radar-bright lake-like depressions: “drained lakes” or “calderas”? Also, “partly-drained”.[2]
- >0.2% lakes coverage -> yet more consistent with Mitri et al. (2007)

Are you convinced yet?



One year at Titan's Arctic

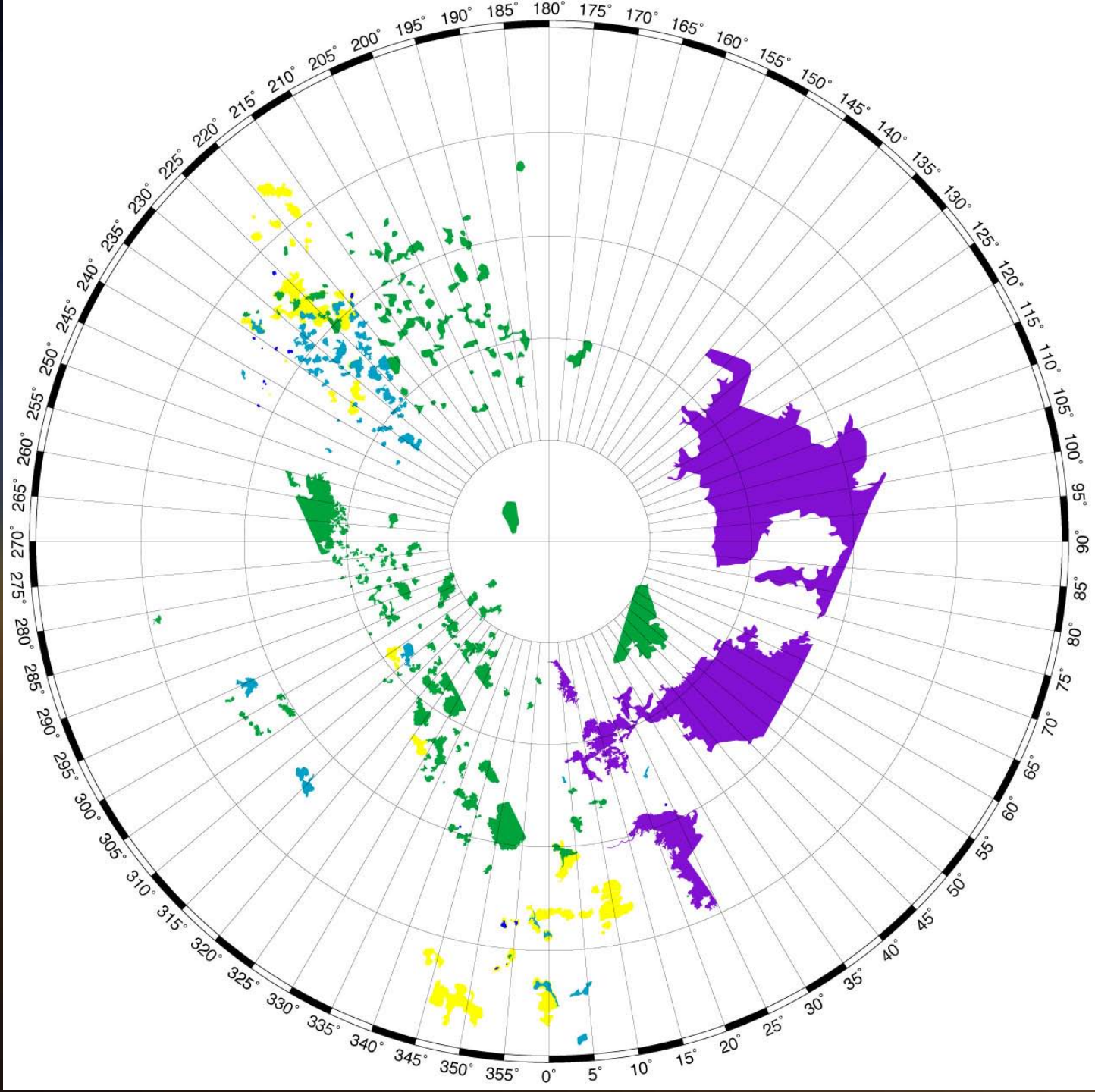
- Landscape geology: context
- 2250 km wide mosaic
- 7 full SAR scenes
- 2 HiSAR images
- 68.8% of >65N imaged
- Little future coverage
- T30 partial confirmation of wider sea interpreted by Turtle et al. from ISS

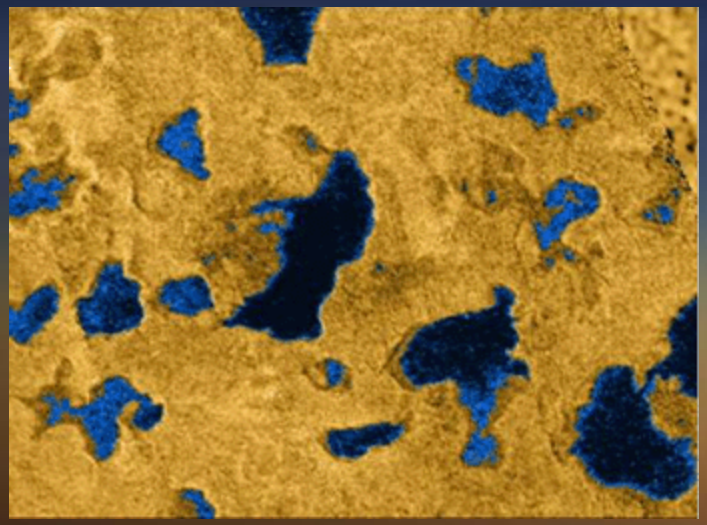


One year at Titan's Arctic (2)

- Classification of lake types:

- Empty
- Steep-sided
- Shallow-sided
- "Seas"



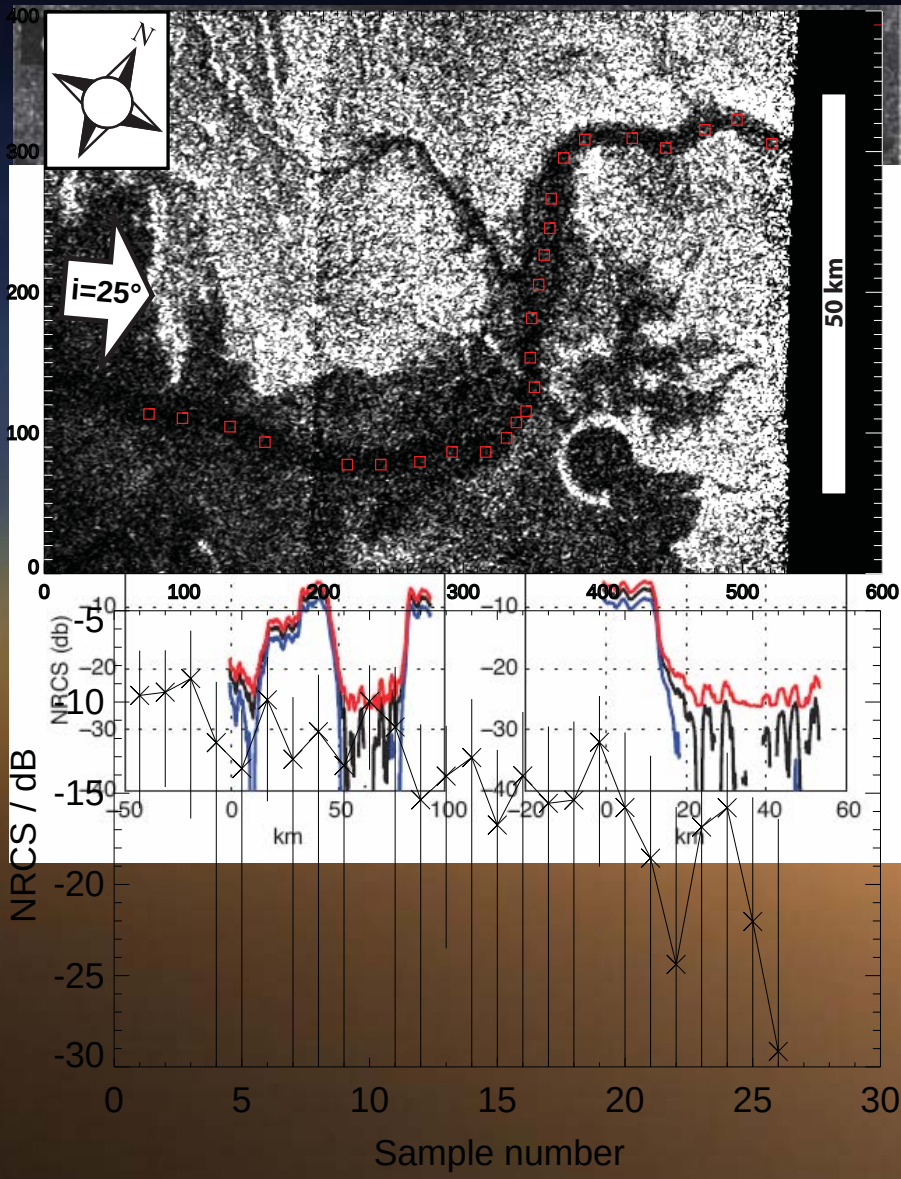


See “Radar Shows Evidence of Seas”

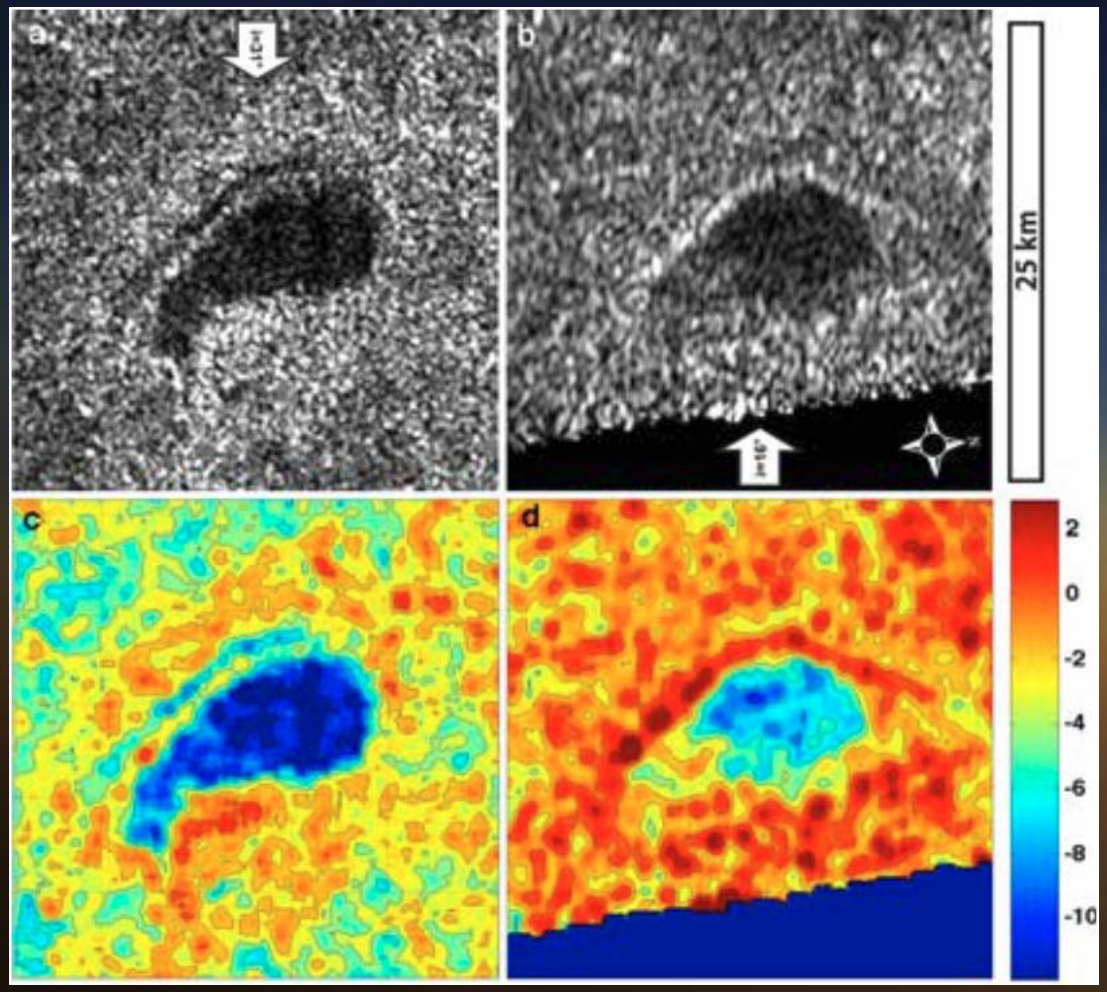
http://saturn.jpl.nasa.gov/multimedia/videos/video-details.cfm?videoID=149

Present-day liquids

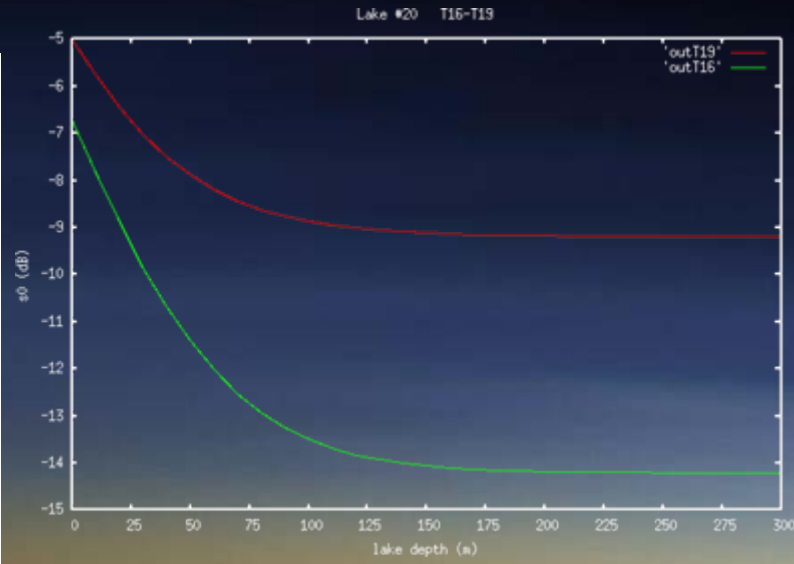
- Synthesis of multiple arguments in favour of these being liquid at present
- Consistency with predictions for present-day conditions
- Dichotomy of bright and dark lakes[d]. Lakes and playas?
- Extremely low microwave reflectivity
- Liquid lakes should be largely transparent to radar
  - Should get darker with depth
  - Diffuse scalloped margins, decrease backscatter towards lake centre
  - We see channels within lakes, but these also get darker as the extend into the body => seeing through more liquid
  - Multi-look observations consistent with radar models …



Multi-look modelling



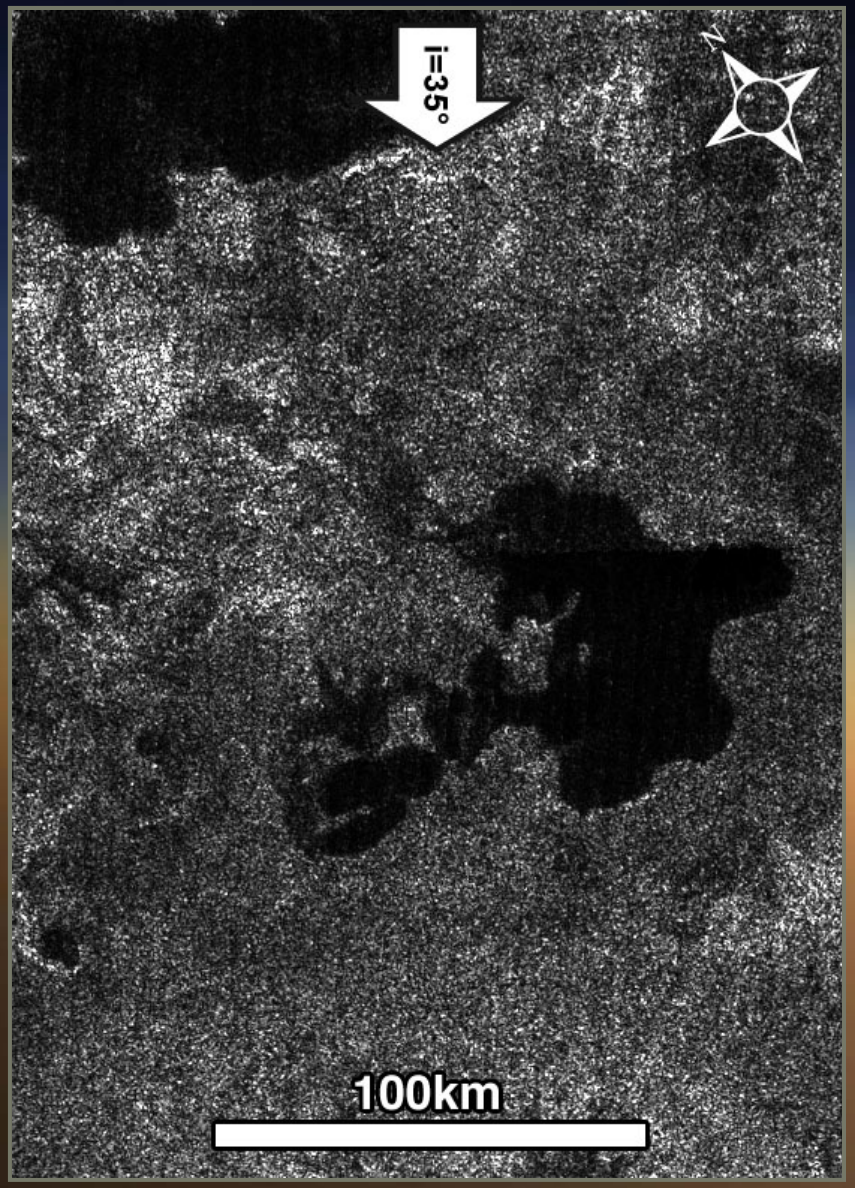
T16 T19



- T16-T19 opposite look
- Brightening could be:
  - Lake level change > 3m
  - Liquid with slope in lake bed
  - Some sort of solid with varying volume scattering
- Still no “smoking gun”

Origin of depressions (1)

- Cryovolcanic: i.e. most steep-rimmed depressions are calderas
  - Close morphological match for some
  - Difficult to account for most lakes. Some are highly irregular but still have rims.
  - Landscape geology?
  - Difficult to account for apparent abundance of calderas at the north pole. Would require some sort of hot pot under the north polar cap. Geophysical explanation not forthcoming.



Origin of depressions (2)

- Karst: the chemical dissolution of an extensive soluble

Consequences of karst

- Requires a methane-soluble substrate
  - Chemistry must be speculated
    - Need sufficient flux and solubility. Not water-ice.
    - Acetylene would be suitably soluble, but acetylene may not be sufficiently stable
    - Aromatic hydrocarbons have been detected, but abundance may not be sufficient.

☐Substance Solids	Flux*4Ga kg on Titan	Dissolved kg in 'ocean' (ppm, μg/g)	Melts K	f_{ocean}	m
Acetylene C_2H_2	5.3E18	1.6E16 *(412)*	192.4	0.05	86
Benzene C_6H_6	1.18E16	7.0E14*(19)*	278.7	0.06	0.14
Propyne $CHCCH_3$	4.0E17	2.4E15*(63)*	170.5	0.006	6.2
Acetonitrile CH_3CN	1.6E16	8.6E14 *(23)*	229.3	0.05	0.24
Propionitrile C_2H_5CN	1.11E16	1.65E15 *(44)*	180.3	0.15	0.14
Hydrogen cyanide HCN	9.3E17	3.2E14 *(8)*	259.9	0.0003	17
CO_2 *	geologic	1.9E15*(48)*	280*	<<1	huge
NH_3**	geologic	4e13-4E15**	176**	<<1	huge

After Raulin (1987) modified by Kargel (2007)

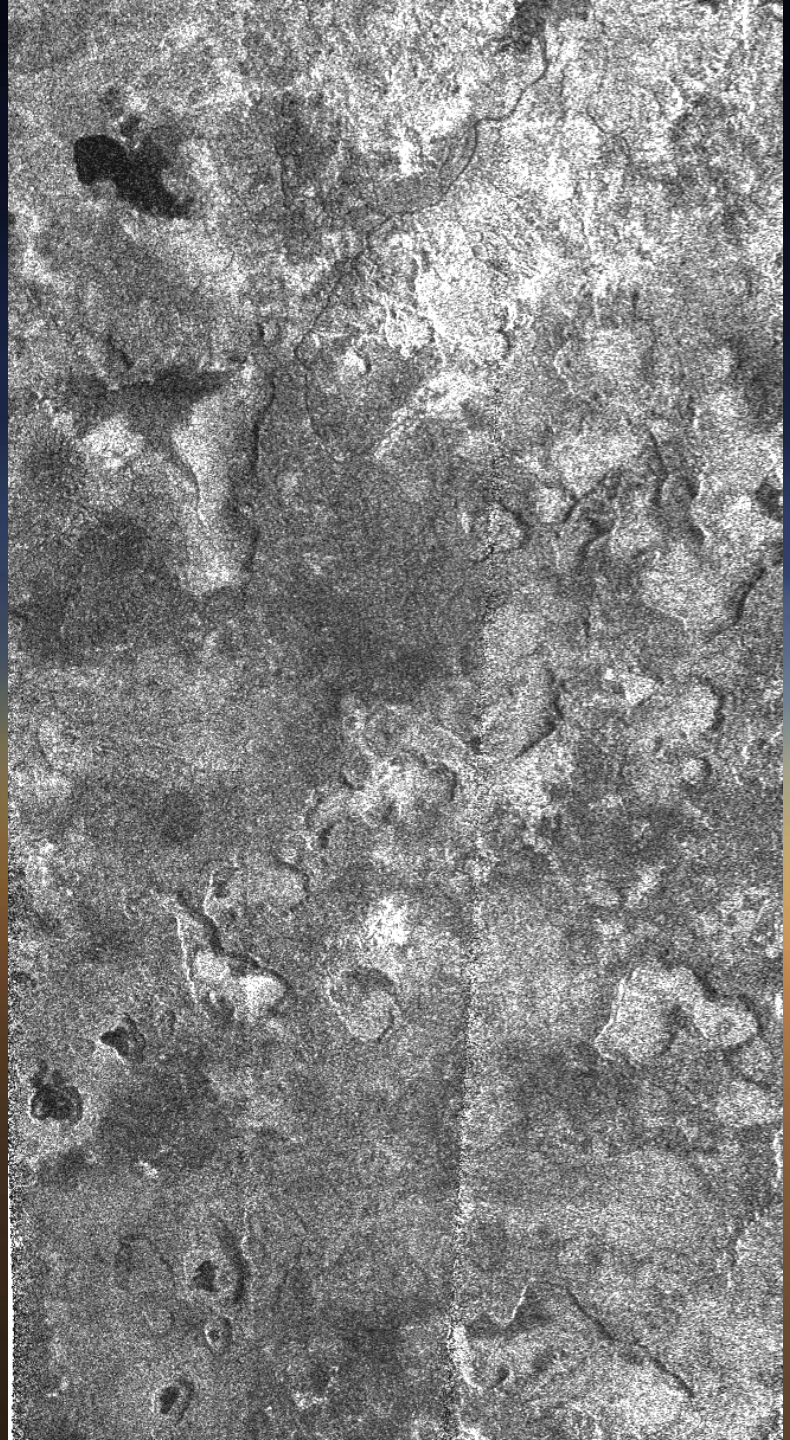
* As CO_2 clathrate and **NH_3 hydrate (Lorenz & Lunine 1996), derived geologically.

Consequences of karst

- If depth of lakes is indicative of the thickness of a non-water-ice soluble layer, then we have an extensive and thick polar cap.
  - Poor thermal conductivity, therefore possible build up of heat leading to more active subsurface chemistry: goos, etc. (Kargel et al., 2006)
  - Possibility of mobile landforms, analogous to glaciers. Separate materials for liquids and solids: differences with terrestrial glaciology.
  - Huge range of possible chemistries.

Drainage

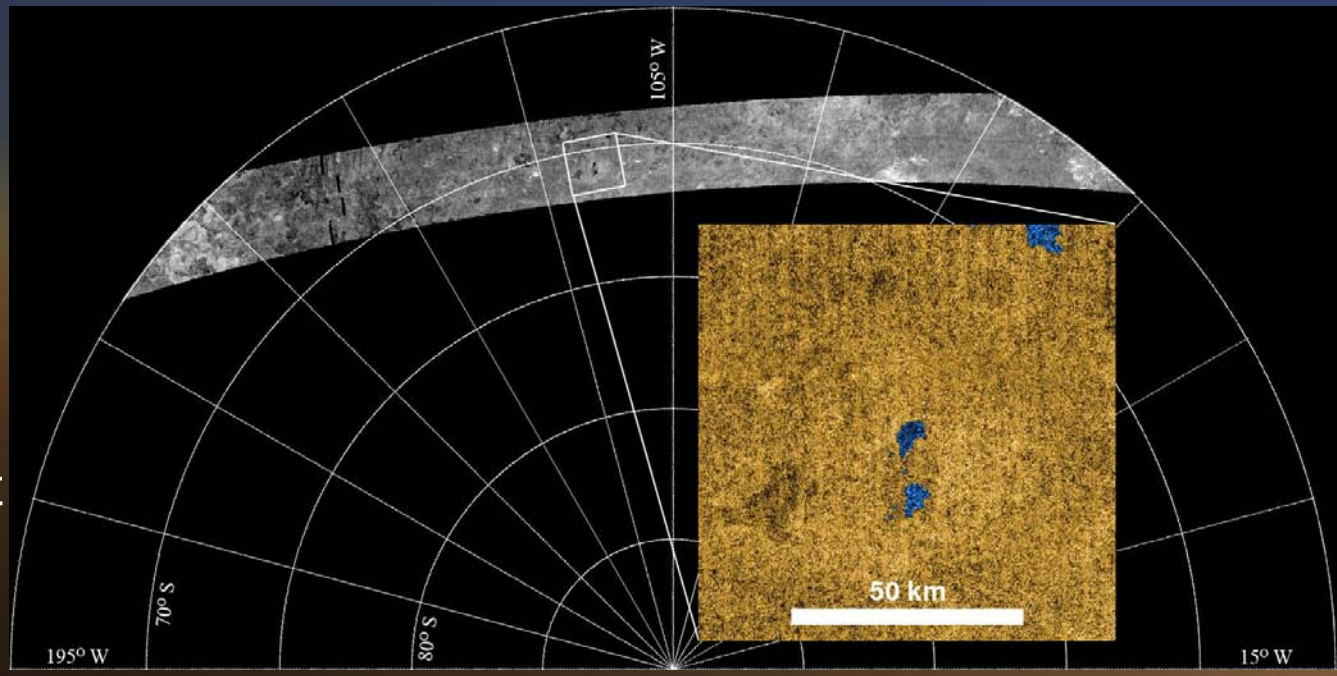
- Terrestrial karst is characterised by highly soluble, well-drained surface geology. As well as lakes and sink-holes, we also find caves.
- Areas of radar-bright lake-like depressions: “drained lakes” or “calderas”? Also, “partly-drained”.[2]
- Complex drainage system, consistent with terrestrial karst regions
- Dichotomy of small lakes and broad seas, with only limited potential for surface connectivity
- Sub-surface flow seems inevitable.



South pole: predictions and first observations

- Lakes thought to be present at south pole.
- ISS observation of “Ontario Lacus”
- Lakes are climate-driven, therefore should persist at both poles.
- Possible differences due t season. No hint of south polar seas.

T36 fly-by, closest approach to the south pole, and first view of Titan’s antarctic



Cassini RADAR Observations: Titan's Hydrocarbon Cycle

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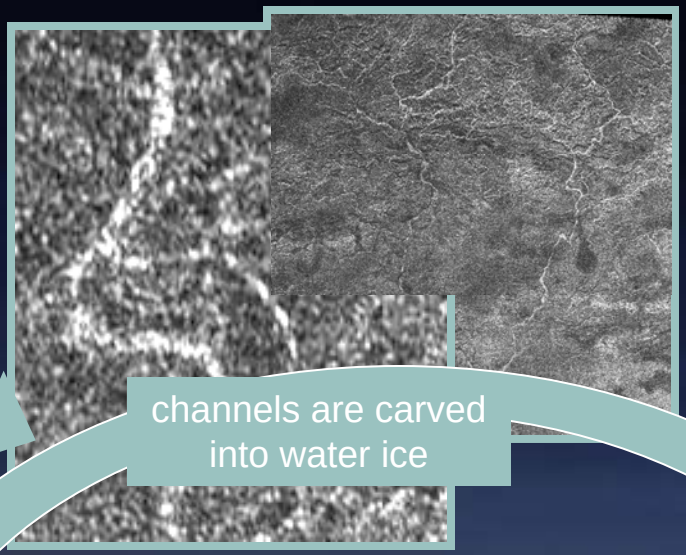

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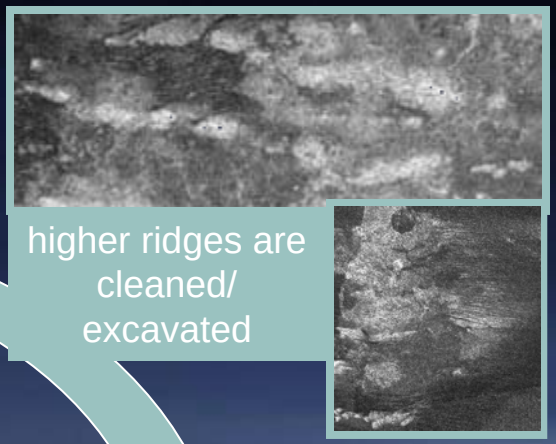

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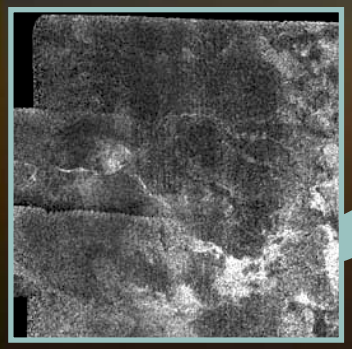

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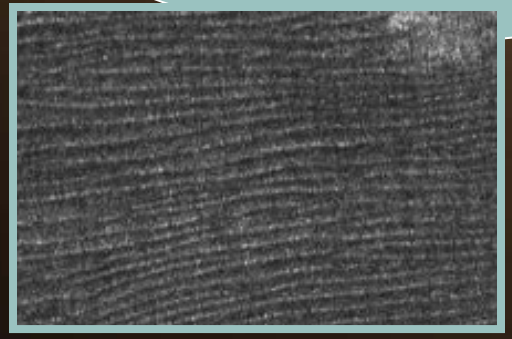

. . . debris also somehow aggregates into ~ 200 μm particles, supplying material from which dunes form

Standing bodies of liquids?

Courtesy S. Wall

Lab measurements are key..

- Physical properties of most non-water-ice candidate materials under Titan conditions are poorly understood
- Experiments requires to understand how materials interact
- … and what they should look like to VIMS and Radar.
- Preliminary work by Paillou et al. has improved understaning of the dielectric properties of liquid lake materials => depth estimates
- Various on-going studies to improve characterisation of spectra at VIMS wavelengths.
- New cryo-ices lab at JPL
  - Ice synthesis
  - Mechanical properties
  - Methane-wetting-angle (with Neish & Lunine at UA)
  - Solubilities and dissolution rates
- Much more…

Conclusions

- Cassini Radar has revealed a unique and geologically rich limnological landscape that demands an explanation.
- These play an important role in the global hydrocarbon cycle on Titan (equivalent to the Earth's water cycle).
- Although there is no smoking gun, every indicator is that the lakes are currently in a liquid state, mostly likely containing methane, ethane and lesser quantitites of dissolved nitrogen and solids.
- The lakes are somewhat transparent to radar, which means we have the possibility to estimate depth in some cases.
- The larger lakes are comparable in extent with great lakes or inland seas on Earth. In terms of fractional coverage some exceed that of the largest inland seas on Earth.
- The origin of the smaller lakes is thought to be largely karstic. Further laboratory work is necessary to test this idea.
- Cryovolcanic or geothermal processes cannot be rules out.

Thanks to…

- Oak Ridge Associated Universities
- Caltech/JPL
- NASA
- The Cassini Project
- Numerous people for informal discussions.