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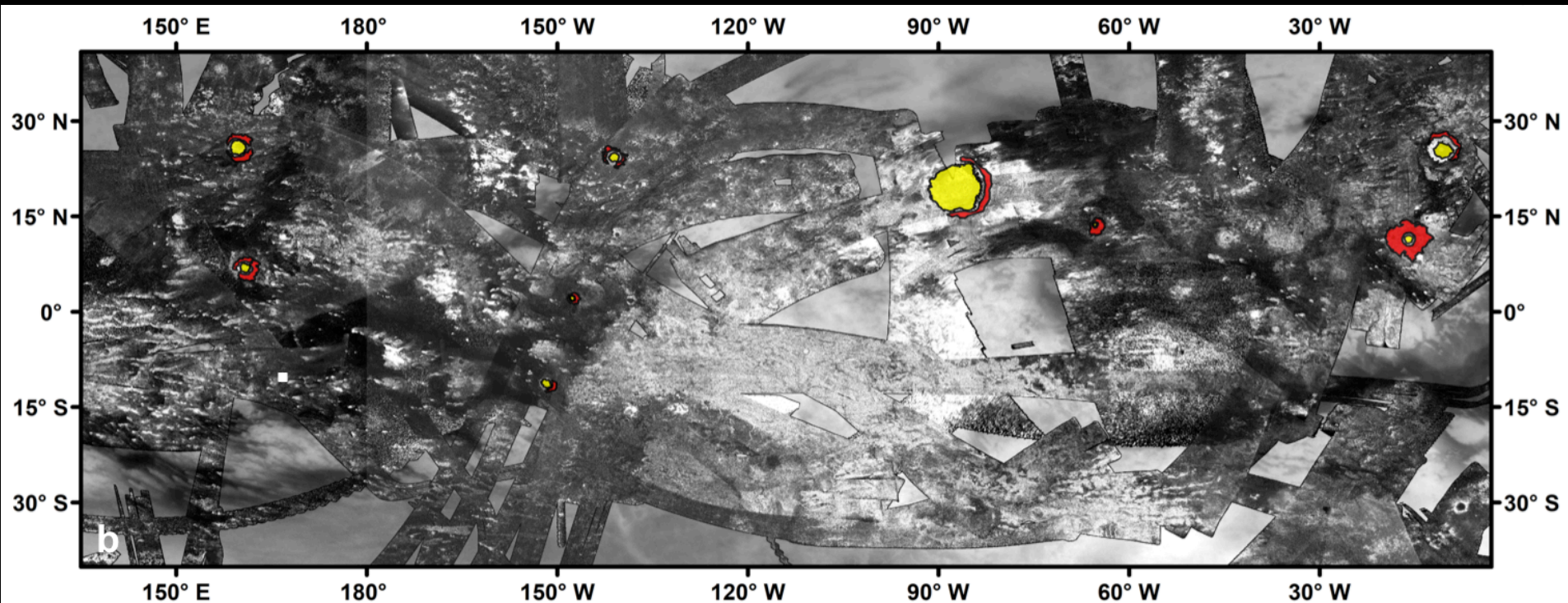
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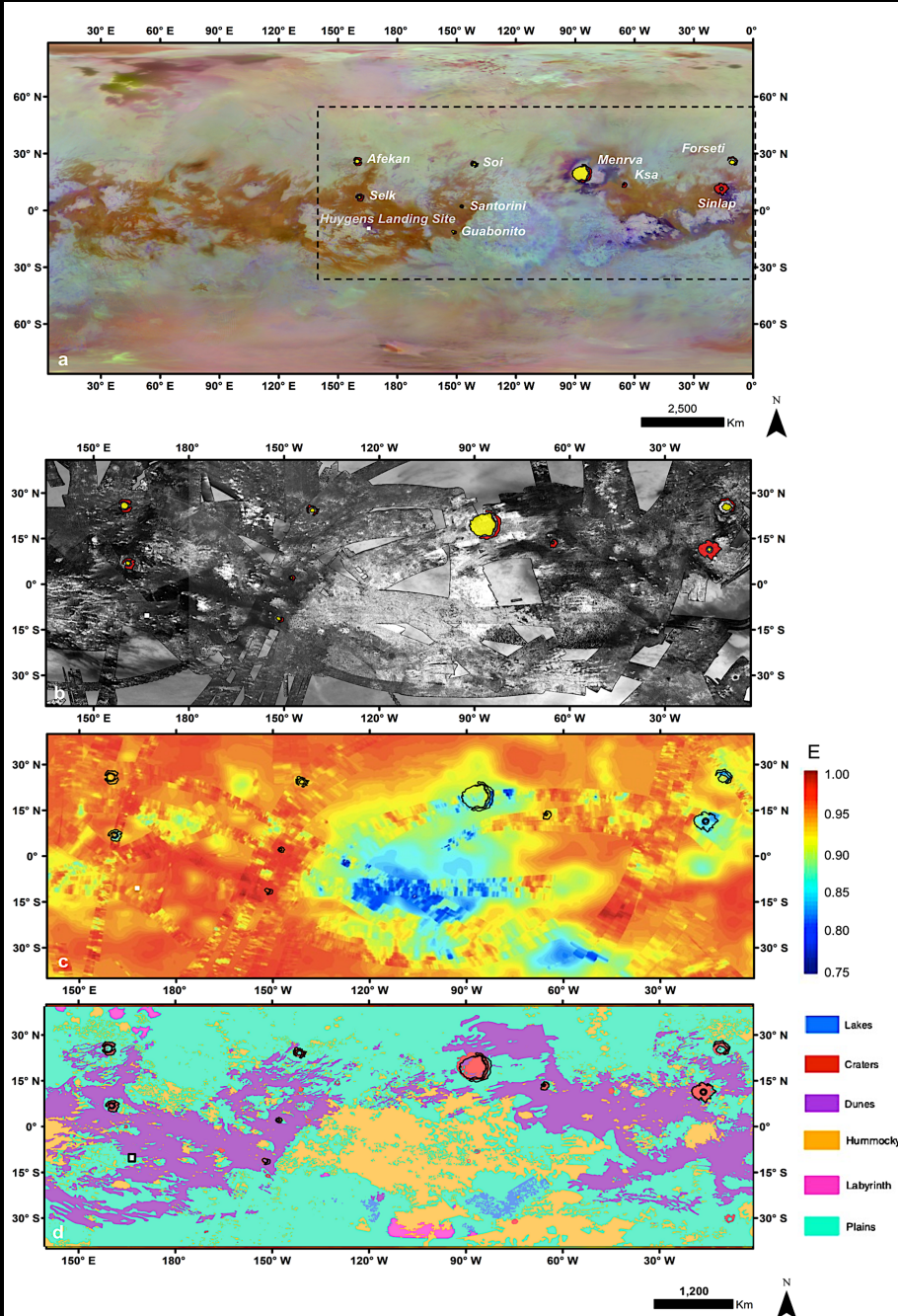
The chemical composition of impact craters on Titan

A. Solomonidou, C. Neish, A. Coustenis, M.J. Malaska, A. Le Gall, R.M.C. Lopes, A. Werynski, K.J. Lawrence, N. Altobelli, O. Witasse, A. Schoenfeld, C. Matsoukas, I. Baziotis, P. Drossart



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9 impact craters for analysis



VIMS RGB

crater floor
ejecta blanket

Dunes craters

- Ksa
- Selk
- Santorini
- Guabonito
- Menrva
- Sinlap

SAR

Plains craters

- Forseti
- Afekan
- Soj

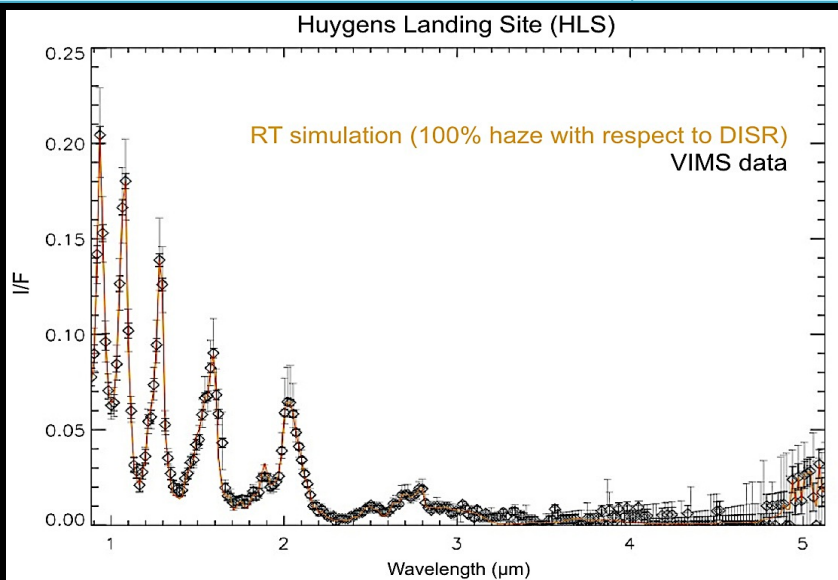
Emissivity
(Janssen et al. 2016)

Major geomorphological units
(Lopes et al. 2020)

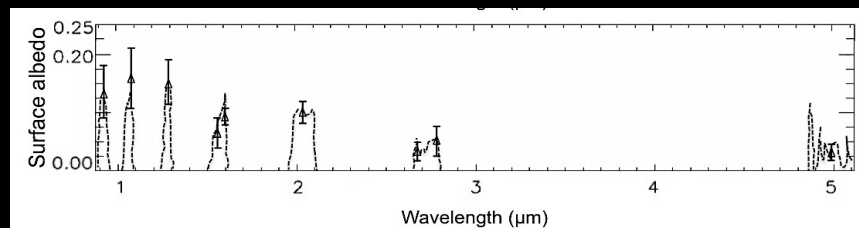
Radiative transfer on VIMS

Hirtzig et al. 2013, Icarus; ; Lopes et al. 2016, Icarus; Bonnefoy et al. 2016, Icarus, Solomonidou et al. 2014, JGR; Solomonidou et al. 2016, 2018, 2019

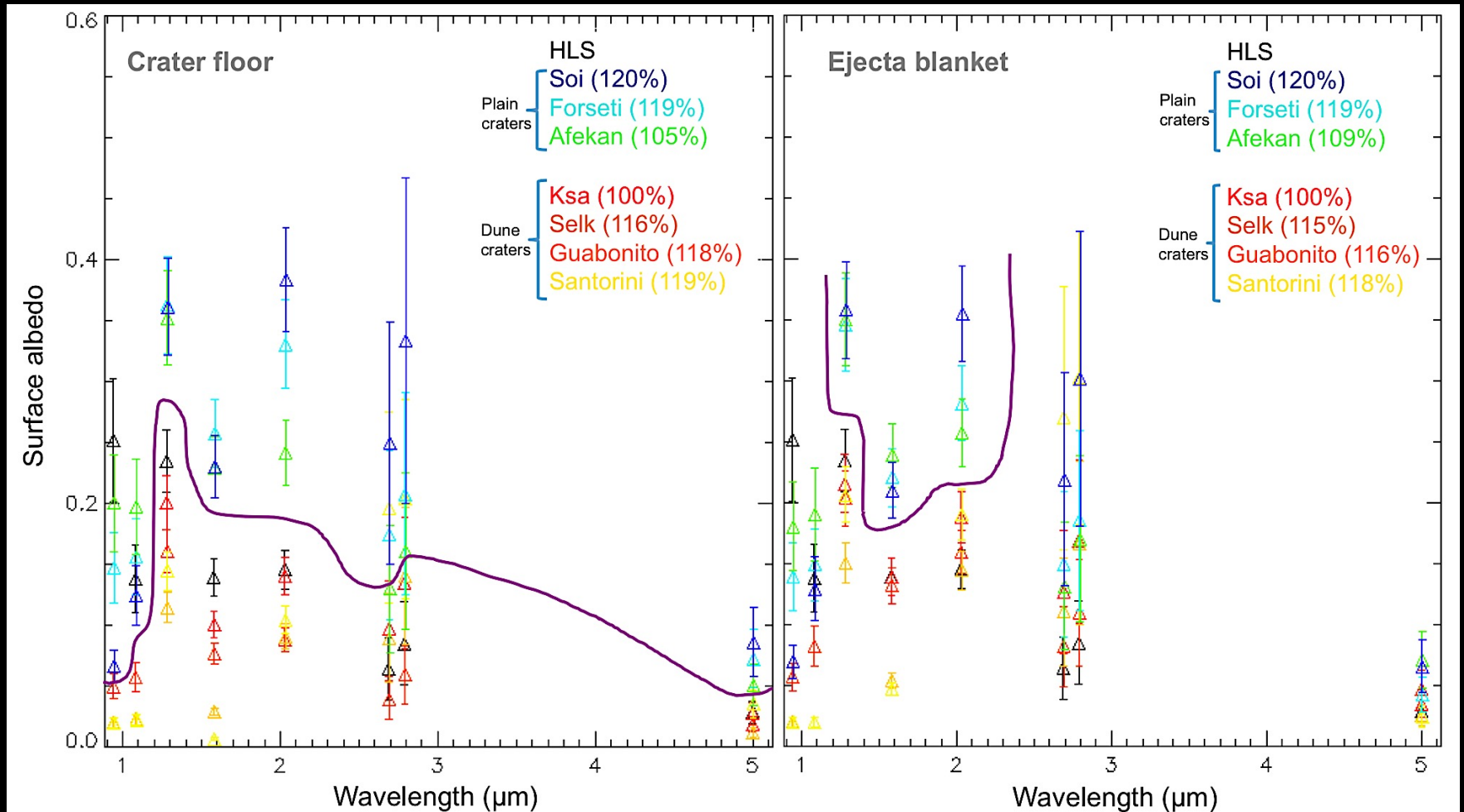
Code Plane-parallel (1D)	
Temperature profile	HASI (Fulchignoni et al. 2005)
CH ₄ mixing ratio	GCMS (Neimann et al. 2010)
Haze parameters	DISR (Tomasko et al. 2008, de Bergh et al. 2011)
Atmospheric gases	¹² CH ₄ , ¹³ CH ₄ , ¹² CH ₃ D, CO, and collisions N ₂ -N ₂ & N ₂ -H ₂ (de Kok et al. 2007; Lafferty et al. 1996, McKellar et al. 1989)
CH ₄ NEW UPDATED absorption coefficients	(Boudon et al., 2006; Campargue et al. 2012, 2015 & Rey et al., 2017, HITRAN, GEISA, etc)
Surface component candidates	ices and tholins (Bernard et al. 2006; Coll et al. 2006; Brassie et al. 2015; B. Schmitt & S. Philippe private communications)



- ✓ Test simulations with various haze opacities
- ✓ Correlation between simulations and data
- ✓ Best fit between VIMS and simulation

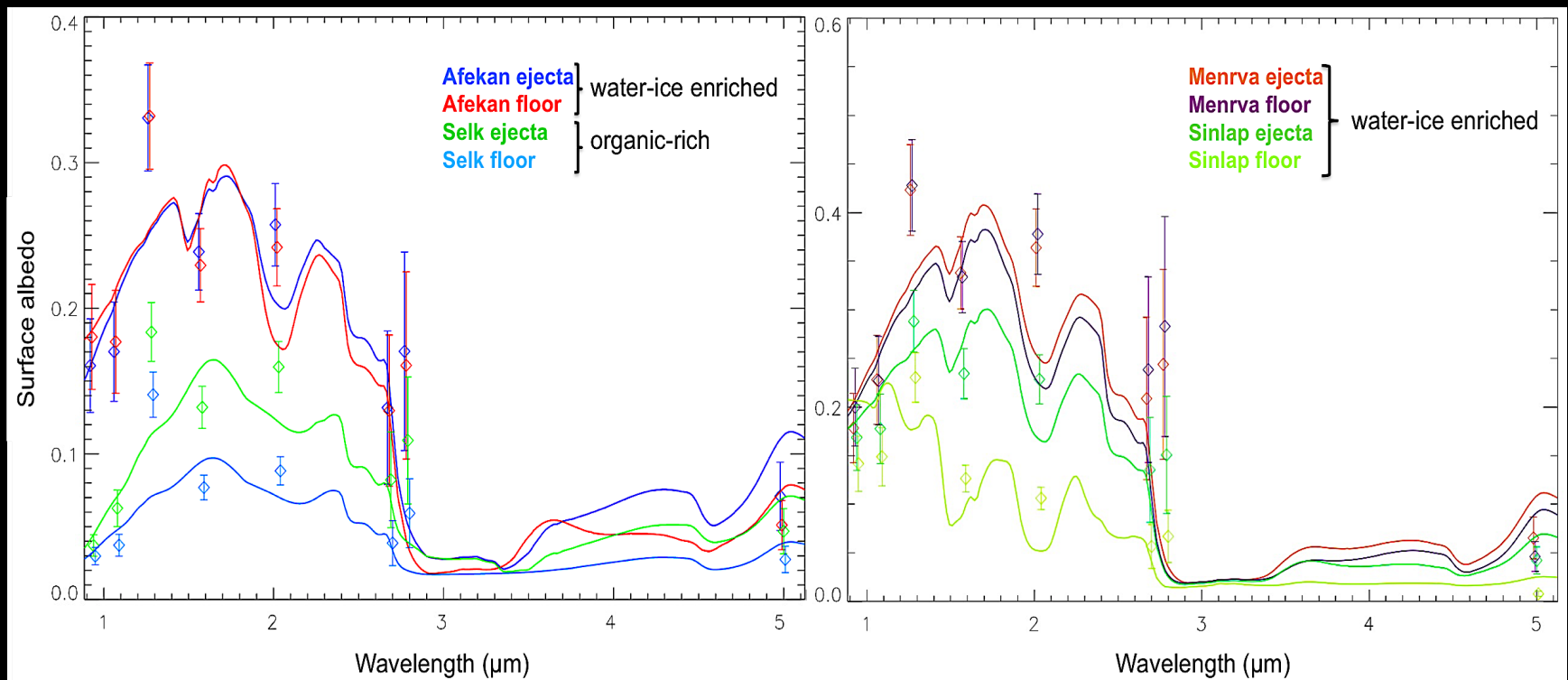


Results – Albedos



Compositional analysis

- ✓ Inferred compositional constraints for 4 different craters (as an example) and their subunits based on the presence of water-ice in their mixtures or its absence.
- ✓ The diamond symbols correspond to the extracted surface albedos, and the full lines to the compositional simulations, which are produced by the code using the best fit attained between the laboratory spectra and the albedos.
- ✓ Afekan is enriched in water-ice and Selk has an organic-rich nature with no obvious water-ice. On the right panel (note the change in scale) we present two craters that differ from the rest on Titan.
- ✓ Both Sinlap and Menrva have signatures of water-ice in their mixtures.



Results – Compositional constraints

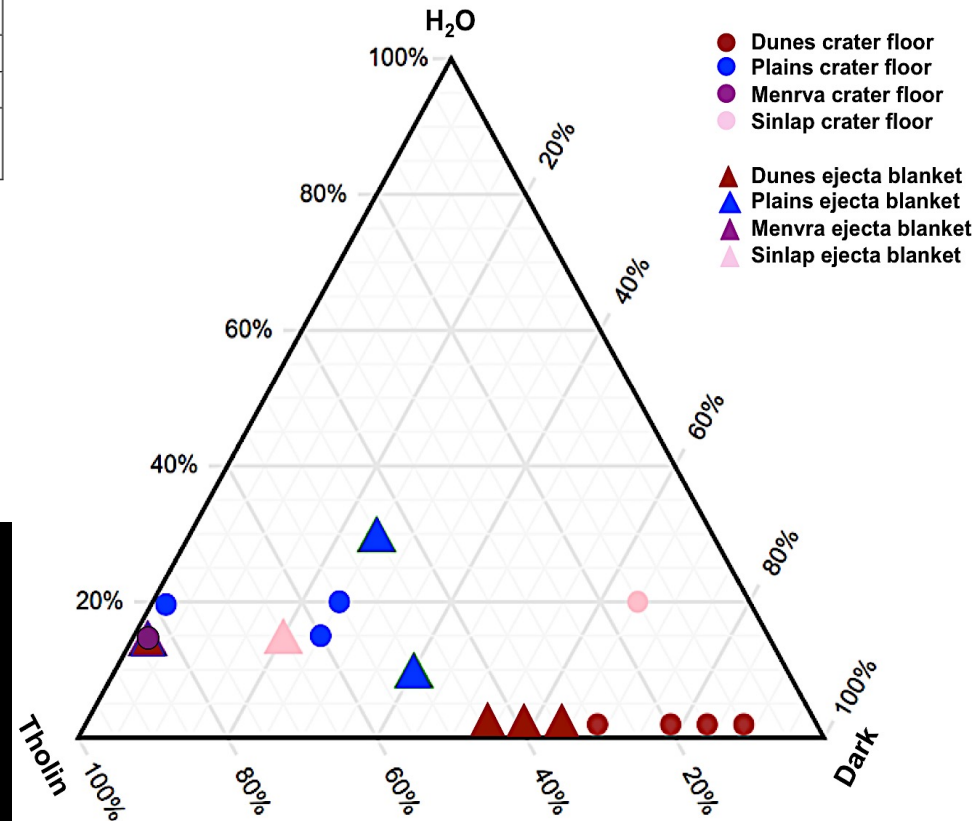
<i>Dunes craters</i>	Ksa		Selk		Santorini		Guabonito	
Unit	f	e	f	e	f	e	f	e
H₂O	-	-	-	-	-	-	-	-
Tholin	15%	45%	20%	35%	30%	40%	10%	40%
Dark	85%	55%	80%	65%	70%	60%	90%	60%
Total Organic	100%	100%	100%	100%	100%	100%	100%	100%
Emissivity	0.92	0.93	0.93	0.85	1	0.95	0.98	0.95
Degradation state	well-preserved		intermediate		degraded		degraded	

<i>Plains craters</i>	Forseti		Afekan		Soi	
Unit	f	e	f	e	f	e
H₂O	20%	30%	15%	10%	20%	15%
Tholin	55%	45%	60%	50%	80%	85%
Dark	25%	25%	25%	40%	-	-
Total organic	80%	70%	85%	90%	80%	85%
Emissivity	0.93	0.83	0.95	0.93	0.93	0.90
Degradation state	intermediate		intermediate		degraded	

<i>Special cases</i>	Menrva		Sinlap	
Unit	f	e	f	e
H₂O	15%	15%	20%	15%
Tholin	85%	85%	15%	65%
Dark	-	-	65%	20%
Total organic	85%	85%	80%	85%
Emissivity	0.90	0.87	0.84	0.85
Degradation state	well-preserved		well-preserved	

Low emissivity values (<0.90) are consistent with an enrichment in water-ice and the high ones (>0.95) with an enrichment in organic materials in the top decimeter of the regolith

The 'total organic' percentages correspond to the expected presence of organics (tholins + unknown dark organic material) in the mixture.



- ✓ Ternary diagram with each of the three apexes representing a composition from the three constituents
- ✓ Overlap between the triangle symbols for the ejecta blanket composition of Santorini & Guabonito and Soi & Menrva.

Conclusions

➤ *The special cases of Menrva and Sinlap :*

= mixture of materials that covers these craters is different than the one covering the others, in nature or in grain size.

✓ Sinlap has a significant amount of dark material (65%) in its c and a nonnegligent amount (20%) in its e.

= difference due to location. Sinlap in Fensal and Menrva in between plains and the dunes.

However, its emissivity is similar to that of Sinlap, suggesting that both craters are a mixture of organics and water-ice.

✓ The presence of water-ice in Sinlap's c and e = youthful age.

✓ No other crater in the dunes fields has any recognizable water-ice signature in its spectra

Sinlap represents how a very young -if not the youngest- impact crater within a dune sea might look.

➤ *The dunes craters :*

✓ Santorini and Guabonito = tholin and dark material NO water-ice.

✓ Emissivity agrees! = organic composition in the near subsurface as well.

✓ For Ksa, Santorini, and Guabonito, the albedo and emissivity values of the crater floors point to an organic nature in the top and near surface composition, suggesting infilling by an organic component such as sand or liquids.

The presence of tholins in the ejecta blankets=chaotic mixing that takes places during the impact process, and/or more atmospheric depositions in the ejecta blankets due to topography.

➤ *The plains craters :*

✓ Unlike most of the dunes craters, they have water-ice in their mixtures

✓ = a mixture of water-ice and organics is being exposed by the craters, and kept relatively "clean" of sediment in the topmost layer of the surface.

The emissivity AGREES! = subsequent infill by organic-rich sediments as the craters become more degraded.

Conclusions

➤ *Proposed scenario for landscape evolution on Titan :*

2 classes of impact craters on Titan: those in the equatorial dunes, and those in the midlatitude plains.

plains craters & Menrva & Sinlap = enriched in an OH-bearing constituent (likely water-ice) in an organic based mixture.

dunes craters = purely composed of organic material (mainly an unknown dark material).

Agreement with Solomonidou et al. (2018), where midlatitude alluvial fans, undifferentiated plains, and labyrinths were found to consist of a tholin-like and water-ice mixture, while the equatorial undifferentiated plains, hummocky terrains, dunes, and variable plains were found to consist of a dark material and tholin-like mixture in their very top layers.

These observations agree with the evolution scenario proposed by Werynski et al. (2019), wherein the impact cratering process produces a mixture of organic material and water-ice, which is later “cleaned” through fluvial erosion in the midlatitude plains. **However, the cleaning process does not appear to operate in the equatorial dunes;** rather, the dunes craters are quickly covered by a thin layer of sand sediment. **This scenario agrees with other works that suggest that atmospheric deposition is similar in the low-latitudes and midlatitudes on Titan, but with more rain falling onto the higher latitudes causing additional processing of materials in those regions (Neish and Lorenz, 2014; Neish et al., 2016; Solomonidou et al., 2018).**

Dunes craters = fast aeolian process and less fluvial erosion

Plains craters = fluvial erosion and slow aeolian sediment transport

Active processes are working to shape the surface of Titan, and it remains a dynamic world in the present day.

This is a hypothesis that will be tested by the Dragonfly mission, which aims to investigate the crater Selk during its prime mission.