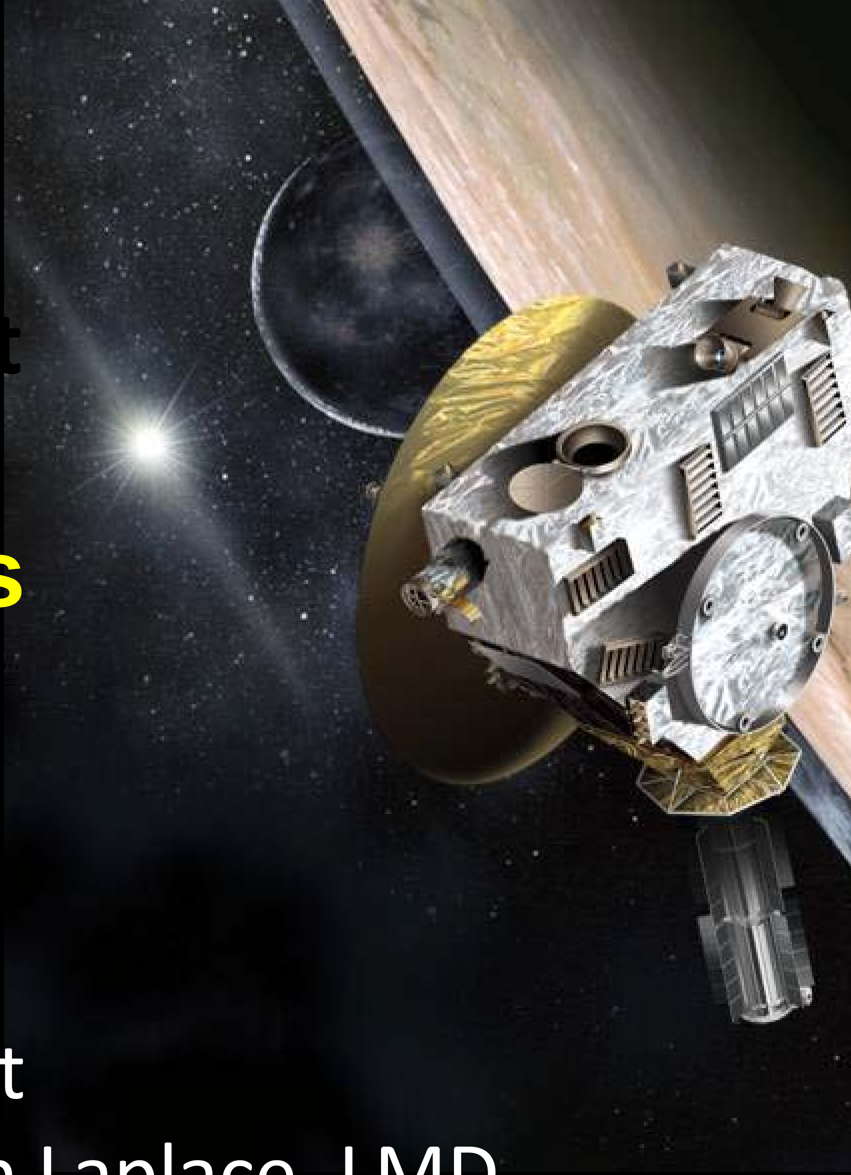
Pluton révélee par la mission New Horizons *et la simulation numérique…*



François Forget
CNRS, Institut Pierrre-Simon Laplace, LMD
(with Tanguy Bertrand, LMD)

Cap Canaveral, january 19 2006

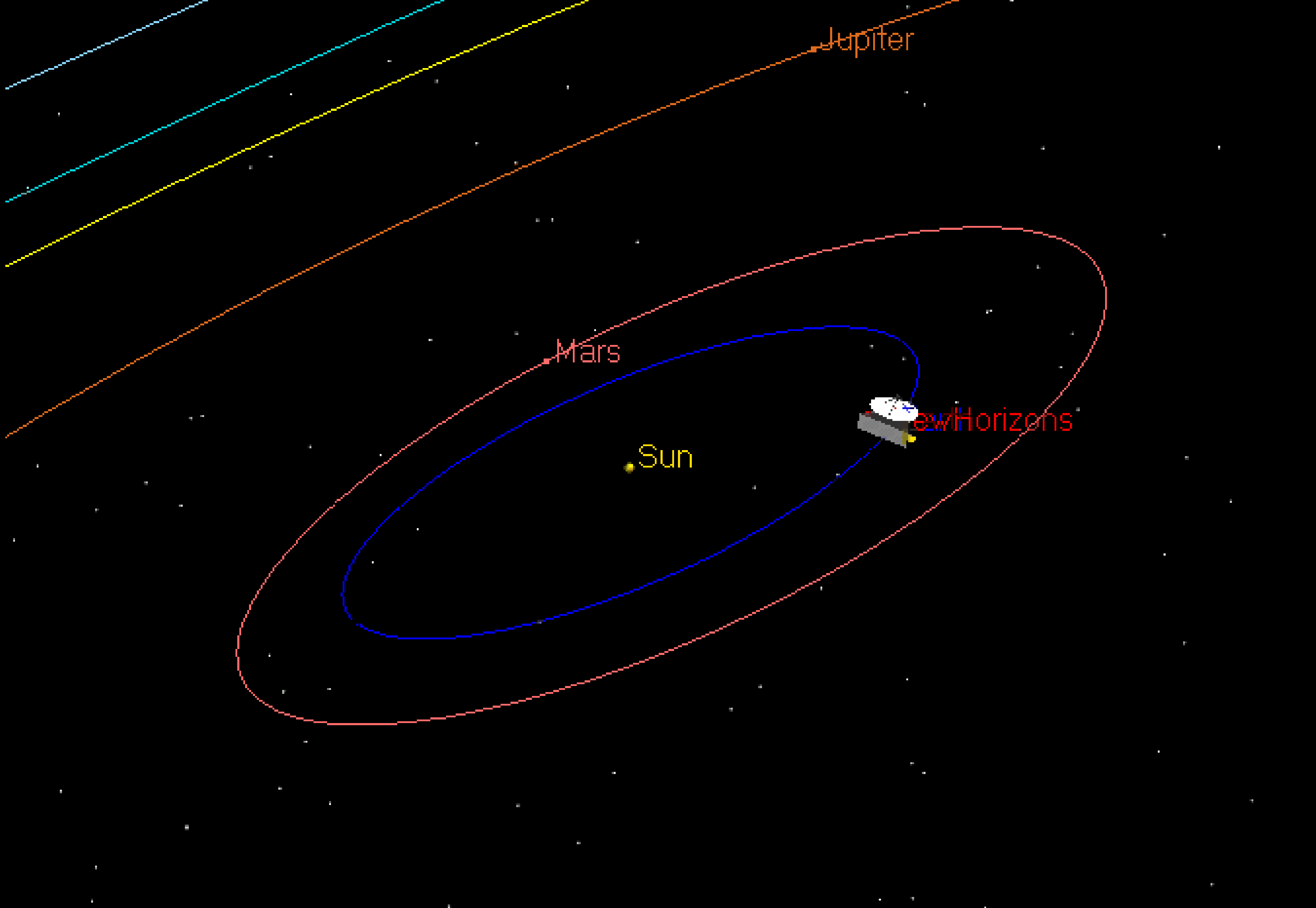
Lanceur Atlas V-551

Capacity: 20 Tonnes in low orbit

New Horizons probe

478 kg

December 2005



Launch 19/01/2006
Jupiter : 28/02/2007

Pluto: 14/07/2015

Pluto-Charon system

Pluto : Ø=2380 km
Charon :Ø~1210 km

Artisteview

1 day Pluto & Charon = 6,4 Earth day

1 an = 247.7 Earth year

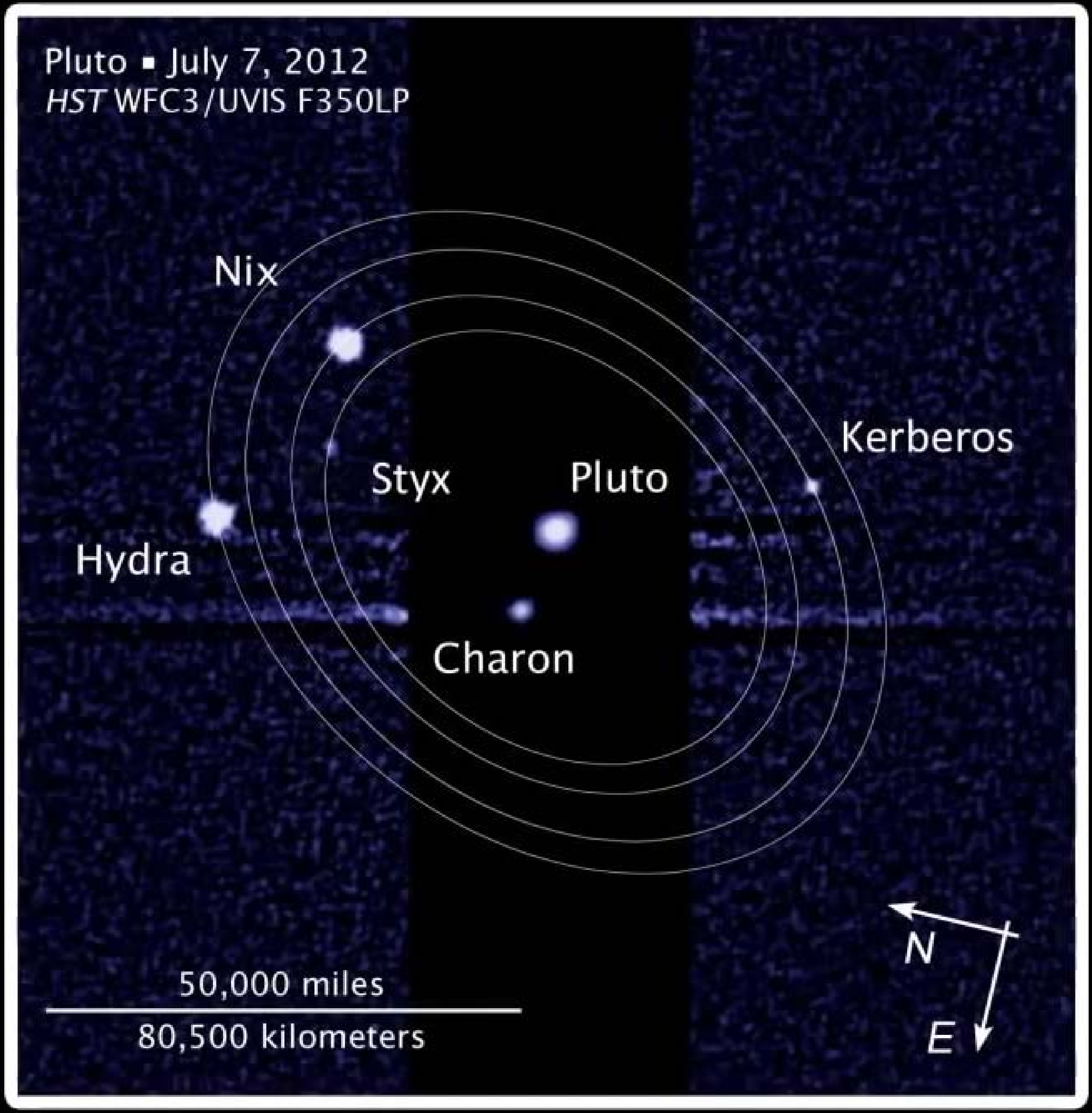
Obliquity = 120°

Perihelion = 29.6 UA

Aphelion=49.3 UA

Several small satellites discovered by the Hubble Space Telescope

- Hydra (2005) ~ 40 km
- Nix (2005) ~50 km
- Kerberos (2011) ~ 10 km
- Styx (2012) ~10 km

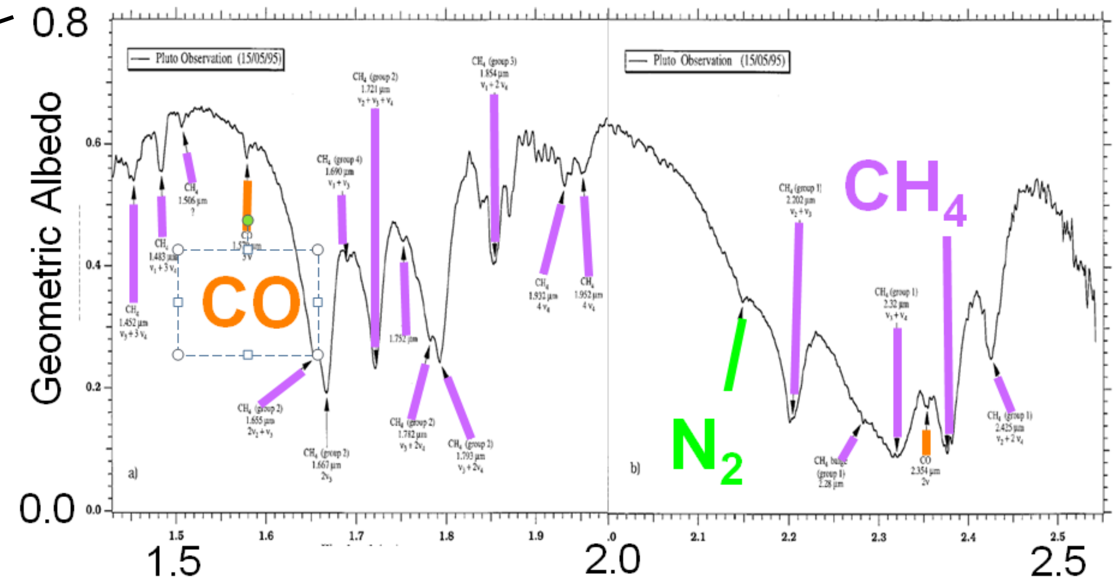


Pluton before2015 *(Hubble Space Telescope)*

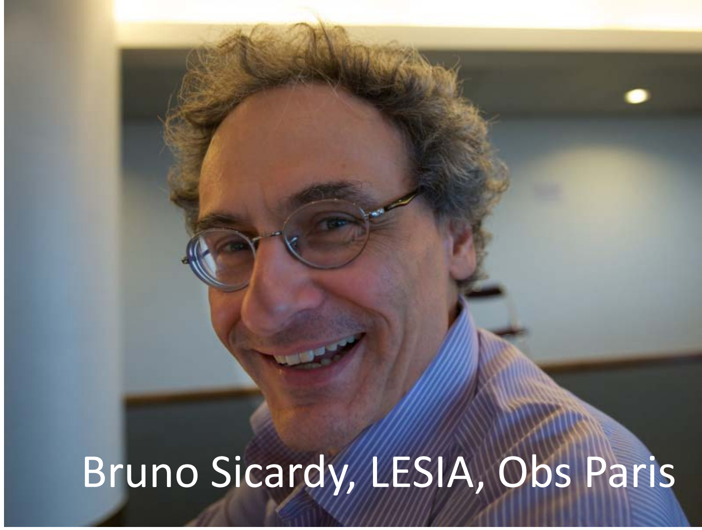
Pluto Spectroscopy before New Horizons: Surface Composition

- **Pluton is covered by N_2, CO, CH_4 ices**
- **Surface Temperature : ~38K (-235° C)**

  ⇨An atmosphere in solid-gaz equilibrium with the surface (N_2 dominated)

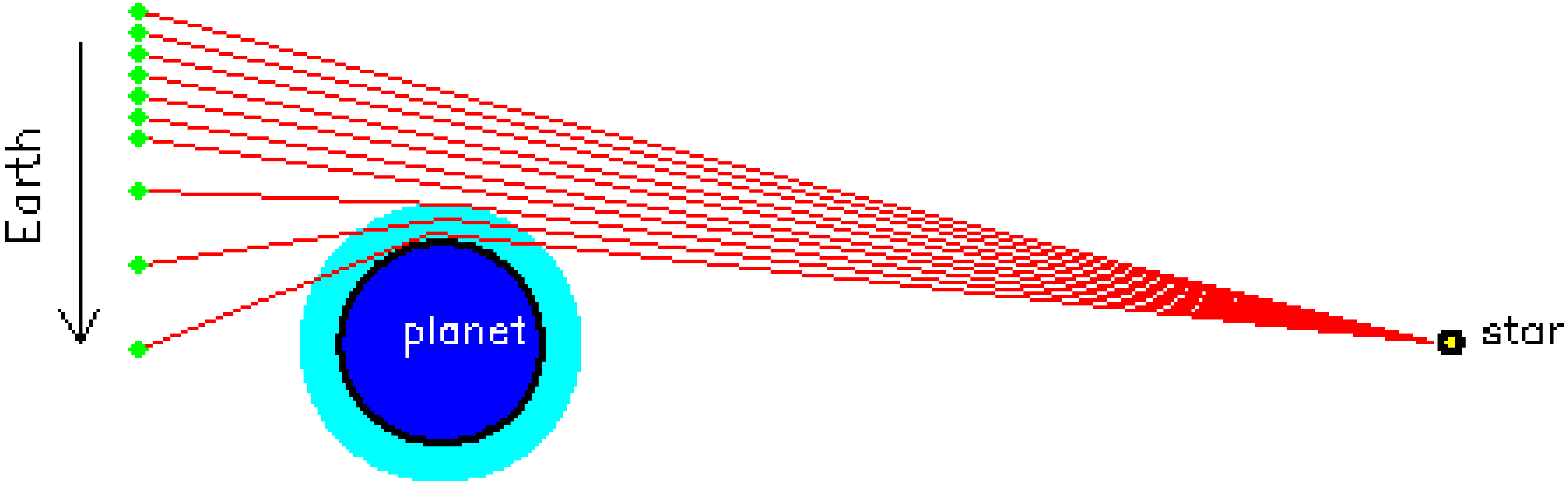


Douté et al 1999

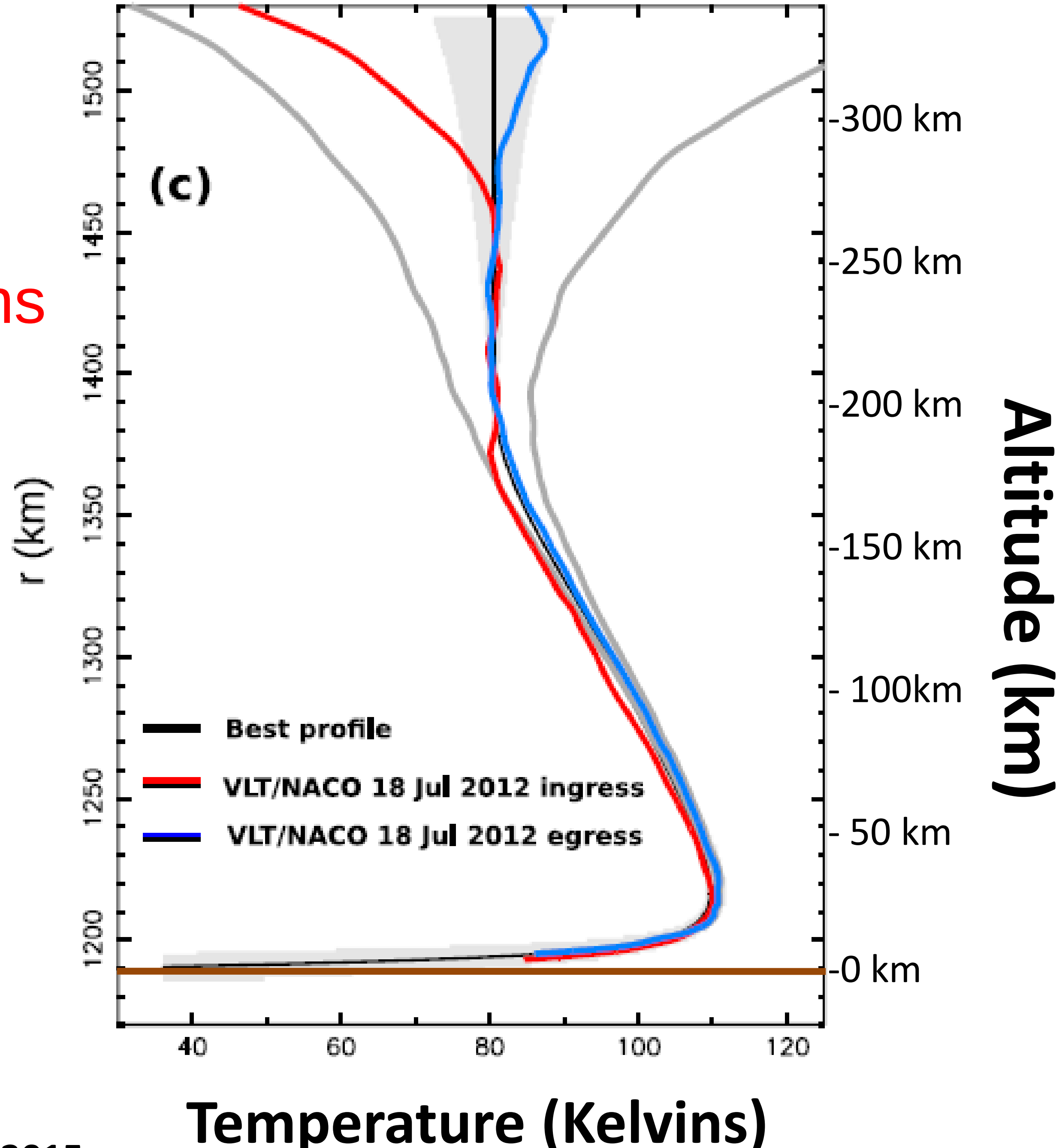


Occultation Stellaire

Discovery of Pluto's atmosphere in 1988
Monitoring of Pluto's surface pressure since 1988
Thermal structure…

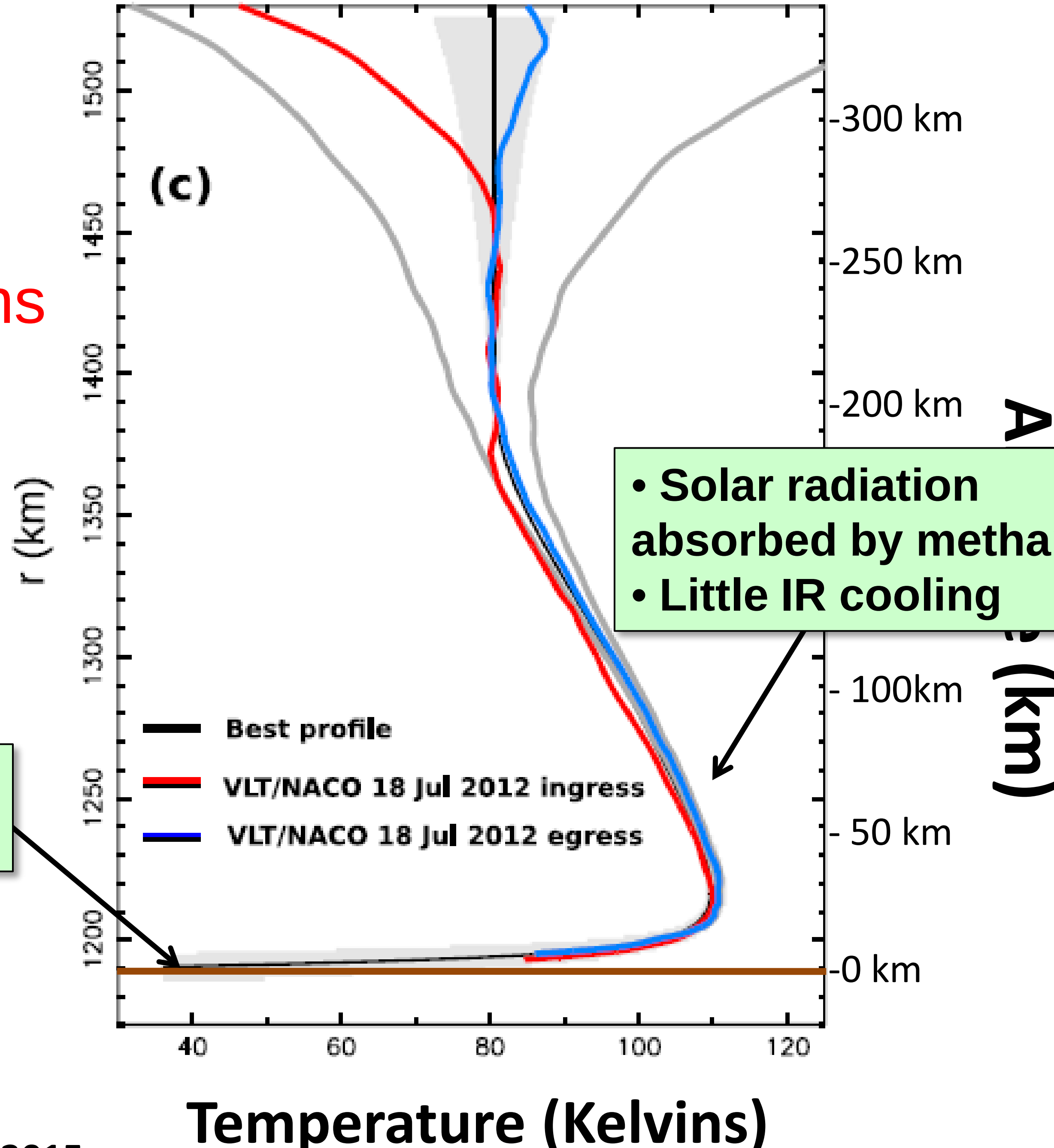


Atmospheric Temperatures measured by stellar occultations



Dias-Oliveira, Sicardy et al. 2015

Atmospheric Temperatures measured by stellar occultations



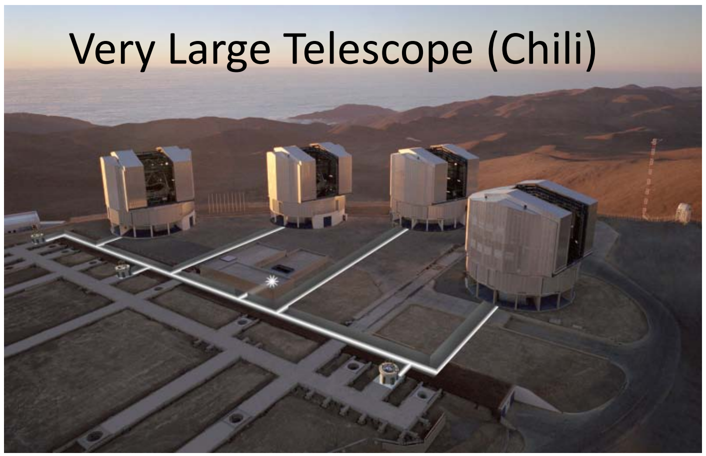
• Solar radiation absorbed by methane
• Little IR cooling

Surface IR cooling

Dias-Oliveira, Sicardy et al. 2015

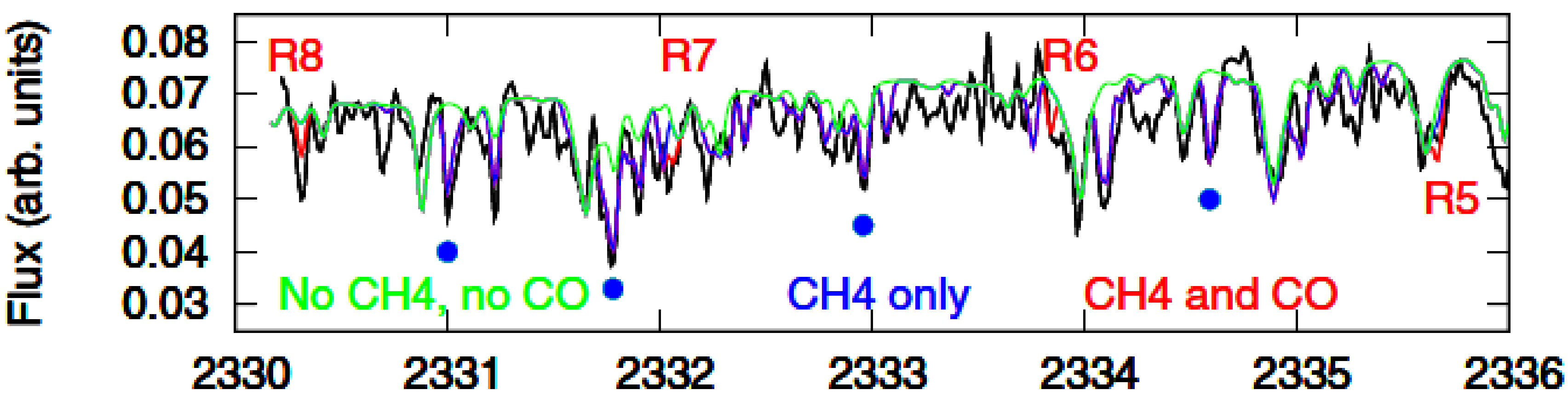
Atmospheric composition by spectroscopy

Emmanuel Lellouch (LESIA, Obs. de Paris)



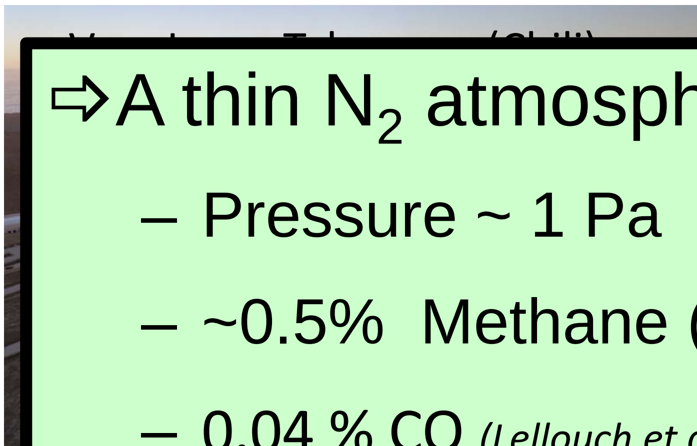
Very Large Telescope (Chili)

Spectromètre CRIRES



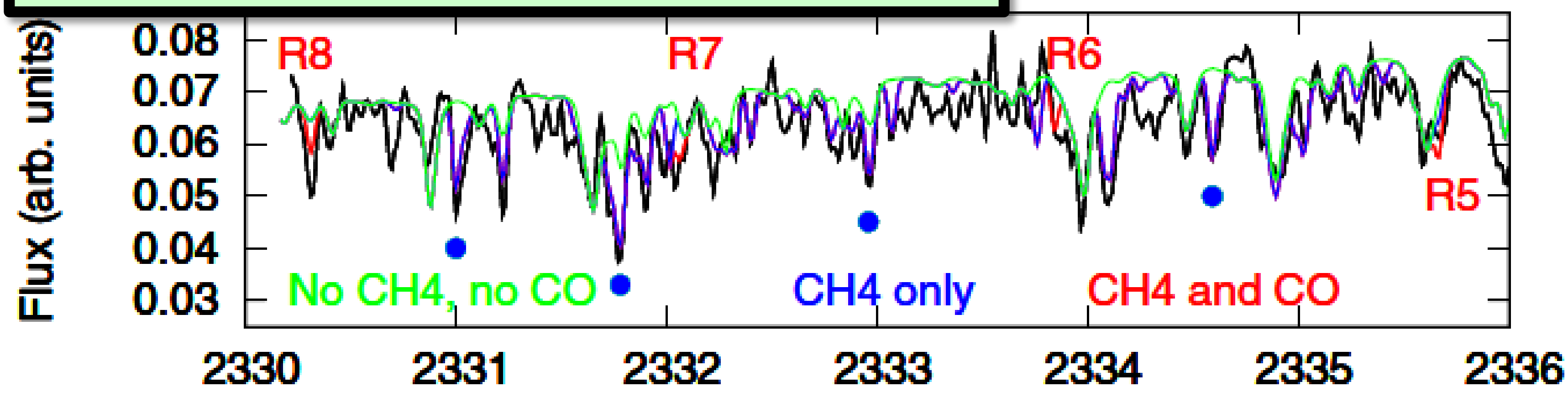
Atmospheric composition by spectroscopy

Emmanuel Lellouch (LESIA, Obs. de Paris)

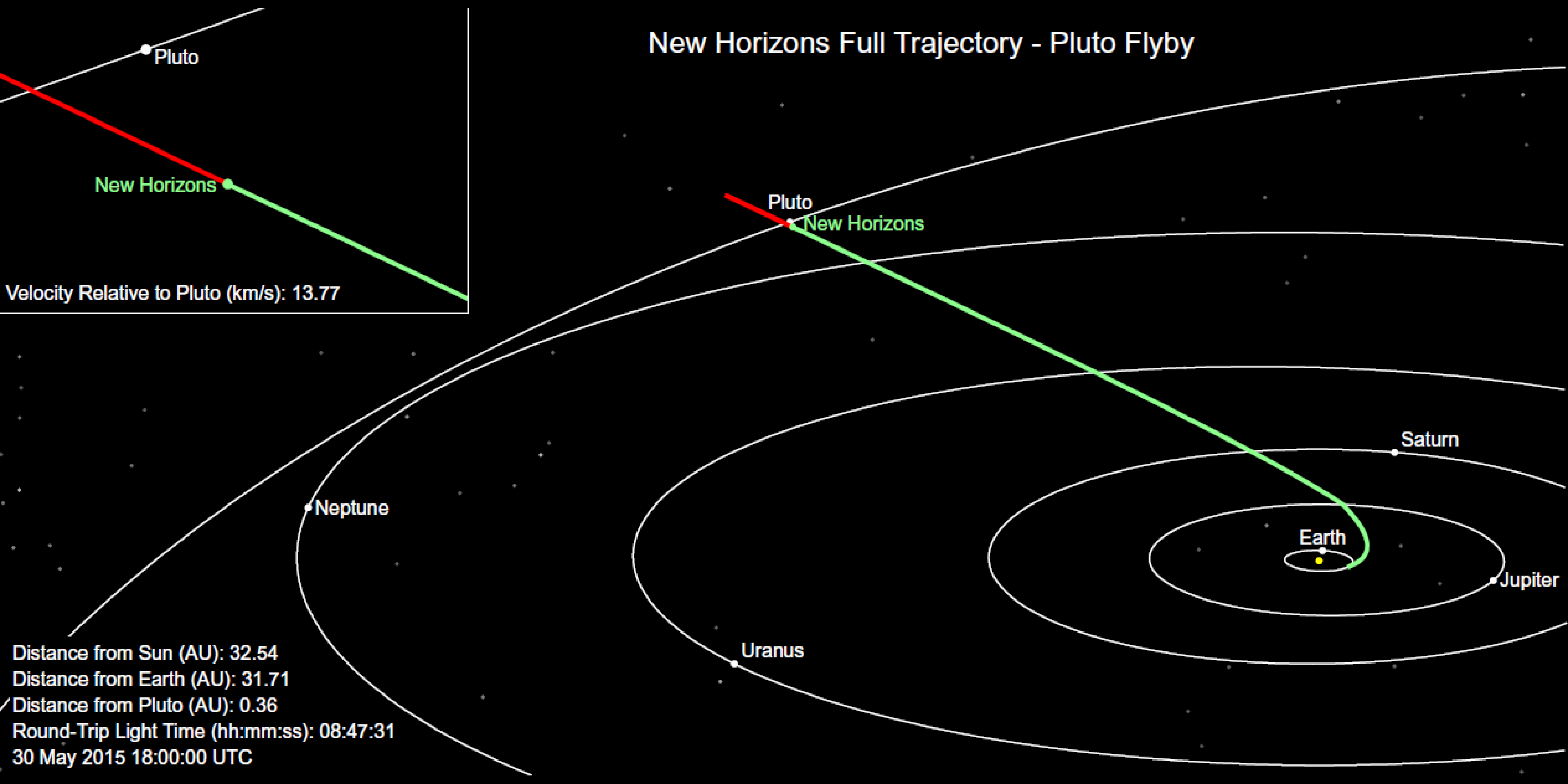


⇨ A thin N_2 atmosphere. Now :

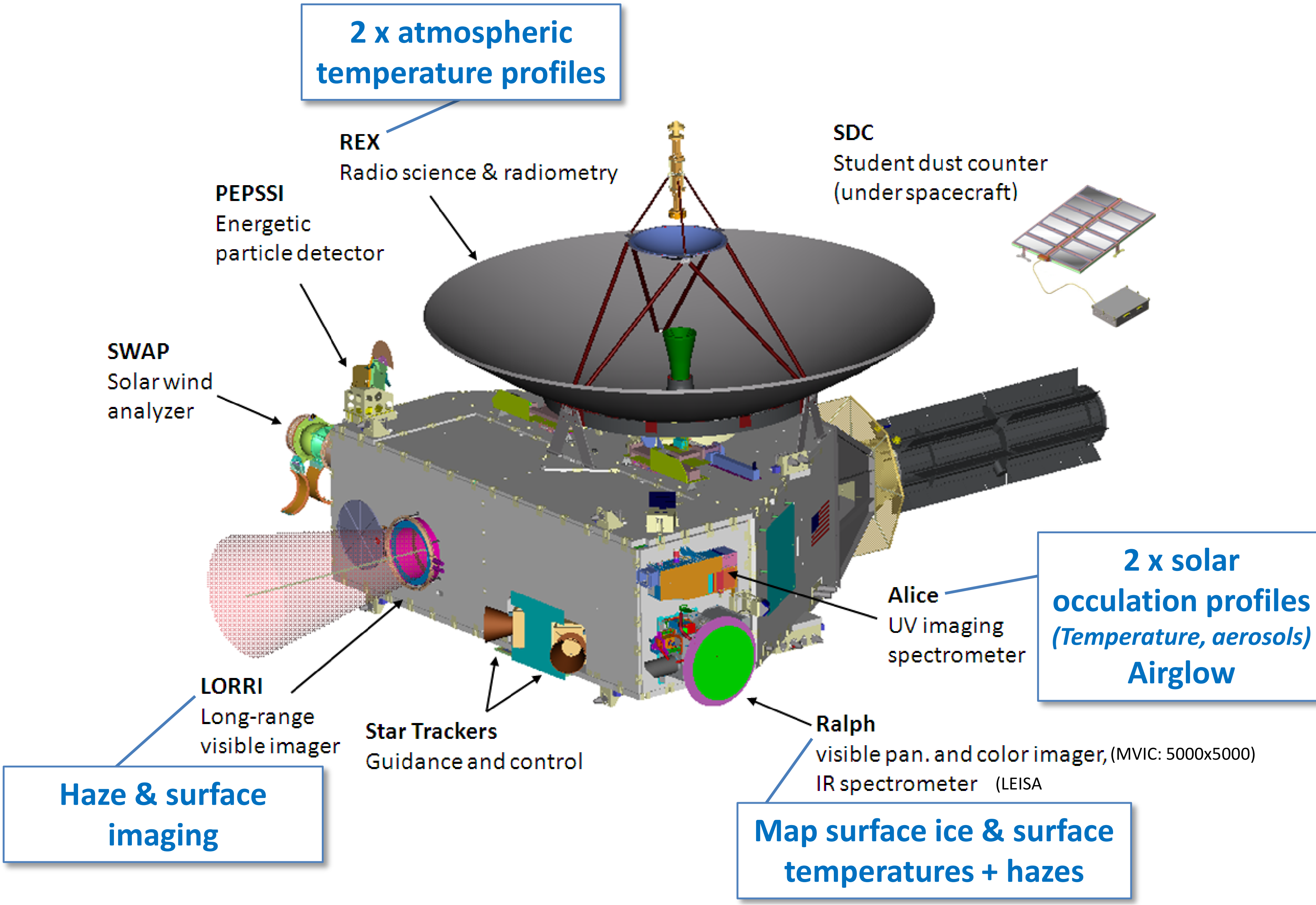
- Pressure ~ 1 Pa
- ~0.5% Methane (CH_4)
- 0.04 % CO *(Lellouch et al. 2009, 2011, 2014)*



Mai 2015: New Horizons is approaching Pluton



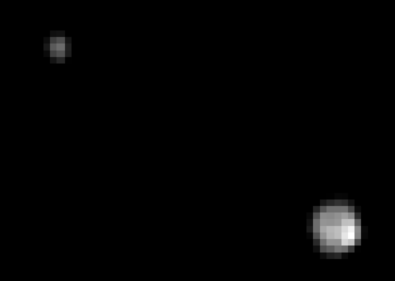
New Horizons



First New Horizons images

Pluto – Charon

LORRI, 12-18 april
(à ~105 millions km)

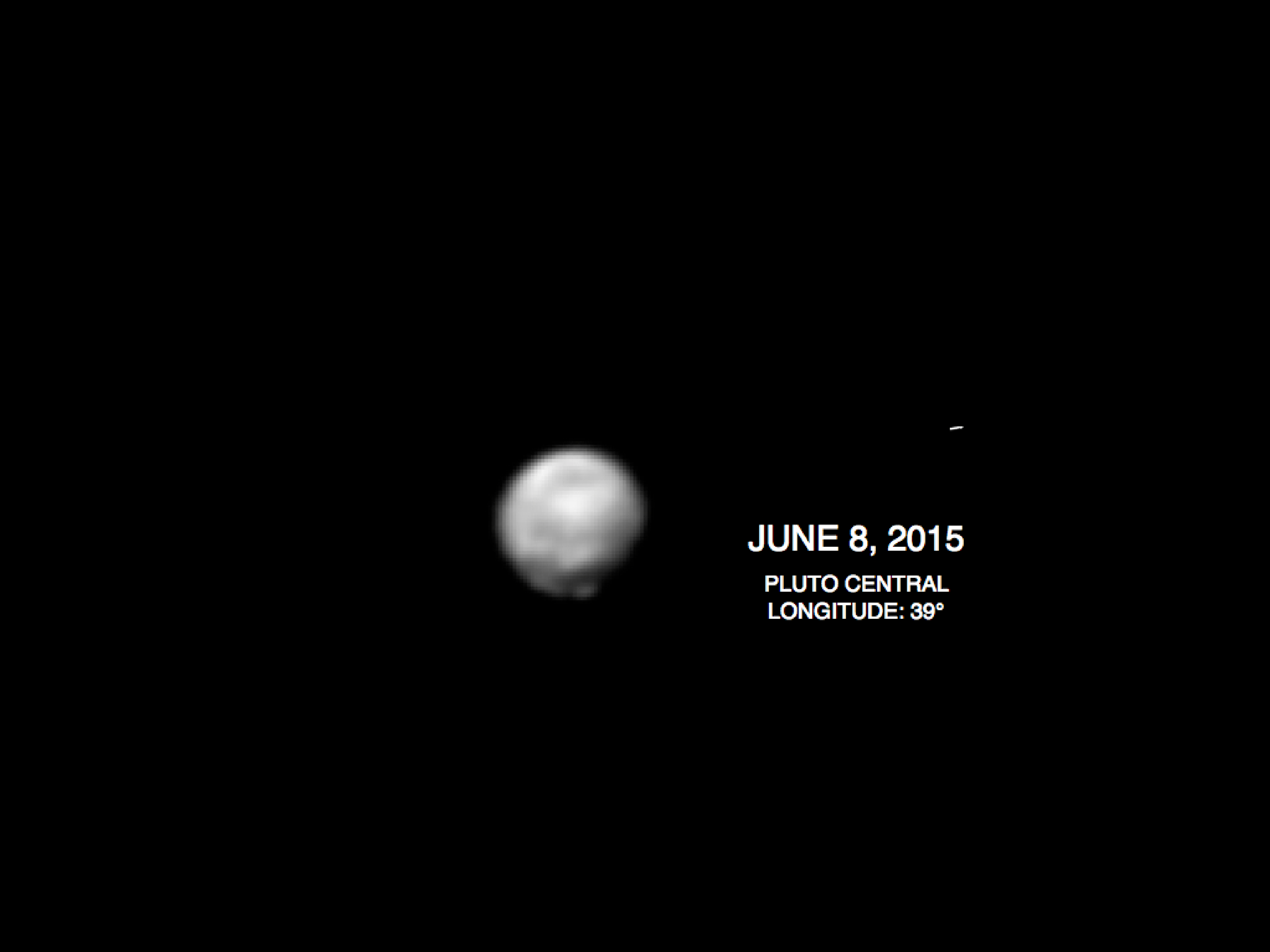


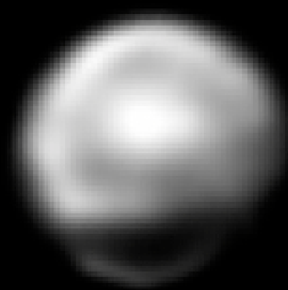
Premières images de New Horizons

Pluton

LORRI, 8-12 mai 2015

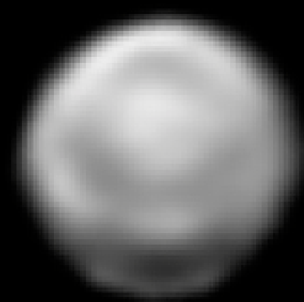
(à ~75 millions km)


JUNE 8, 2015
PLUTO CENTRAL
LONGITUDE: 39°



JUNE 13, 2015

PLUTO CENTRAL
LONGITUDE: 79°



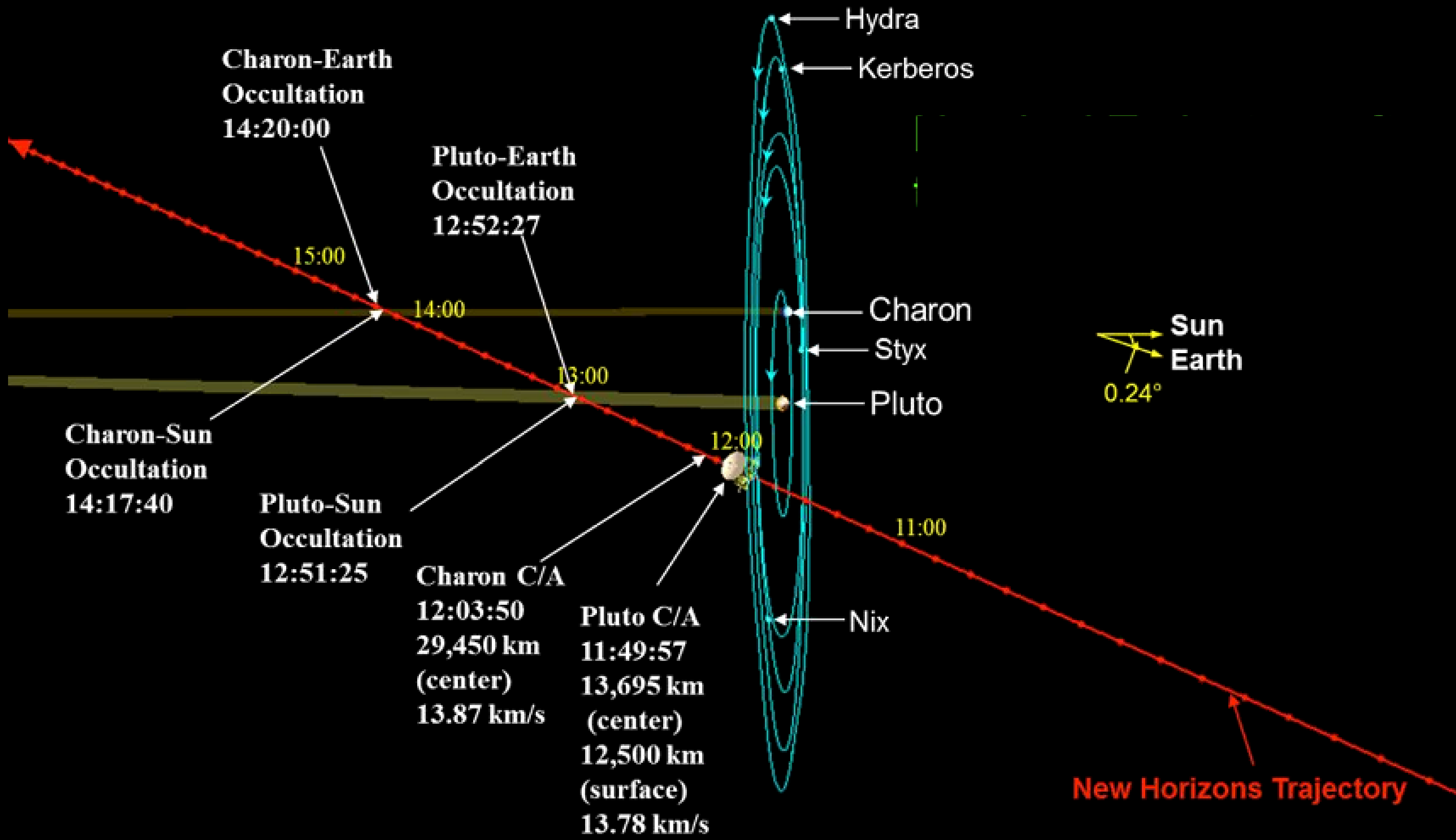
JUNE 15, 2015

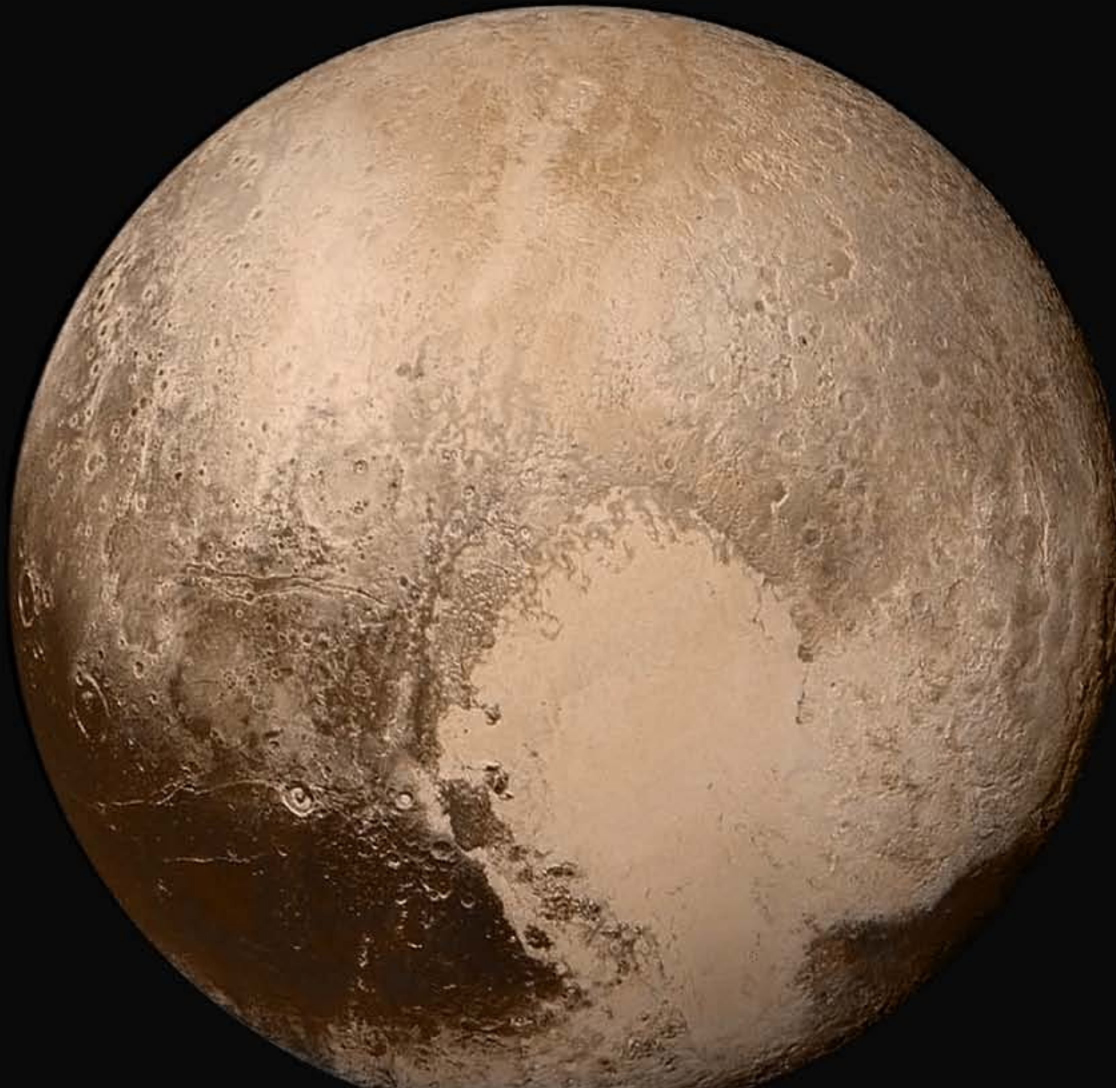
PLUTO CENTRAL
LONGITUDE: 356°

3 juillet 2015
(12.5 million km)

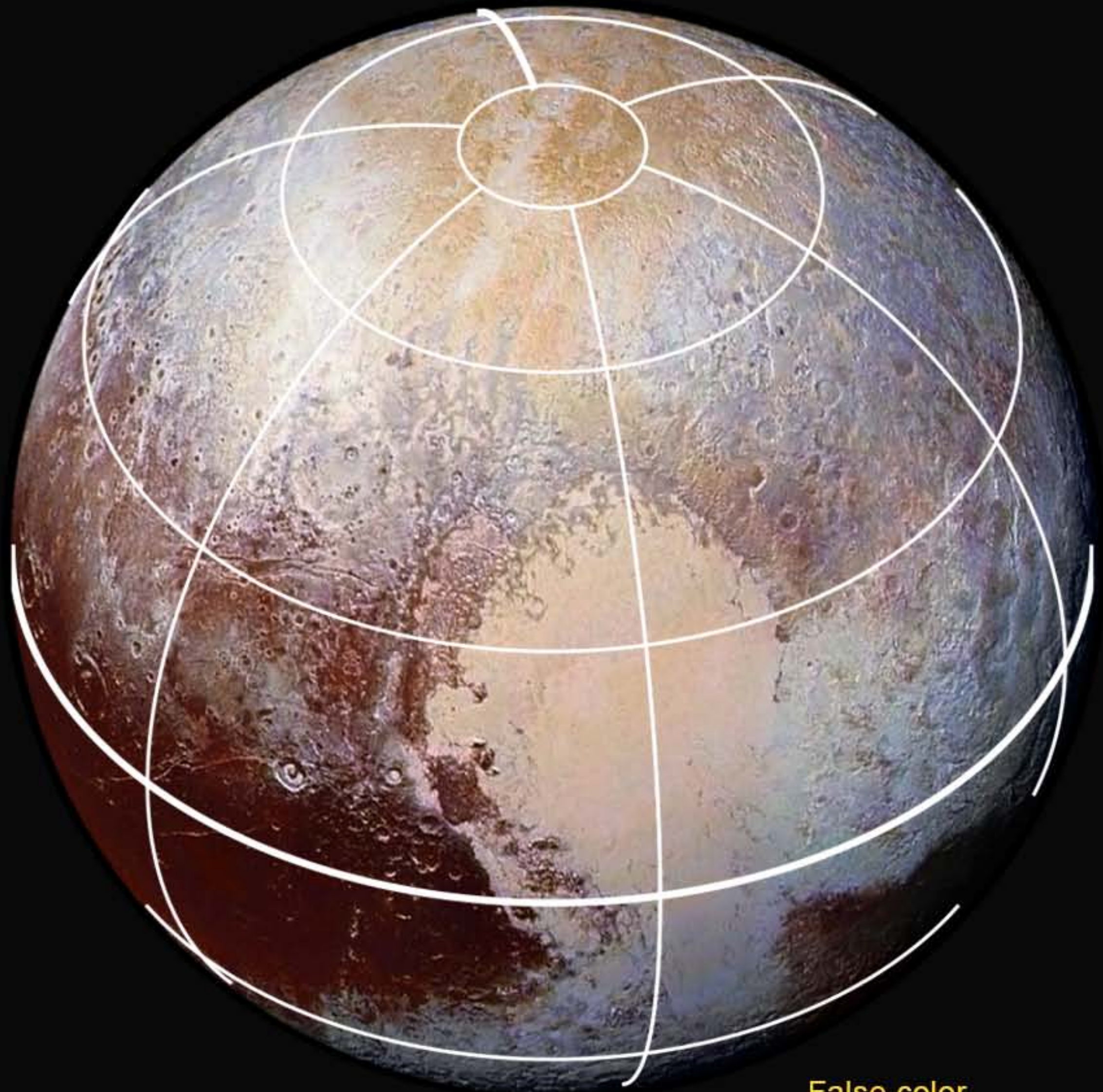
14 Juillet: Pluto fly by

Relative Velocity 13.78 km/s (49,600 km/h) ~10,000 km from Pluto. ~27000 km from Charon

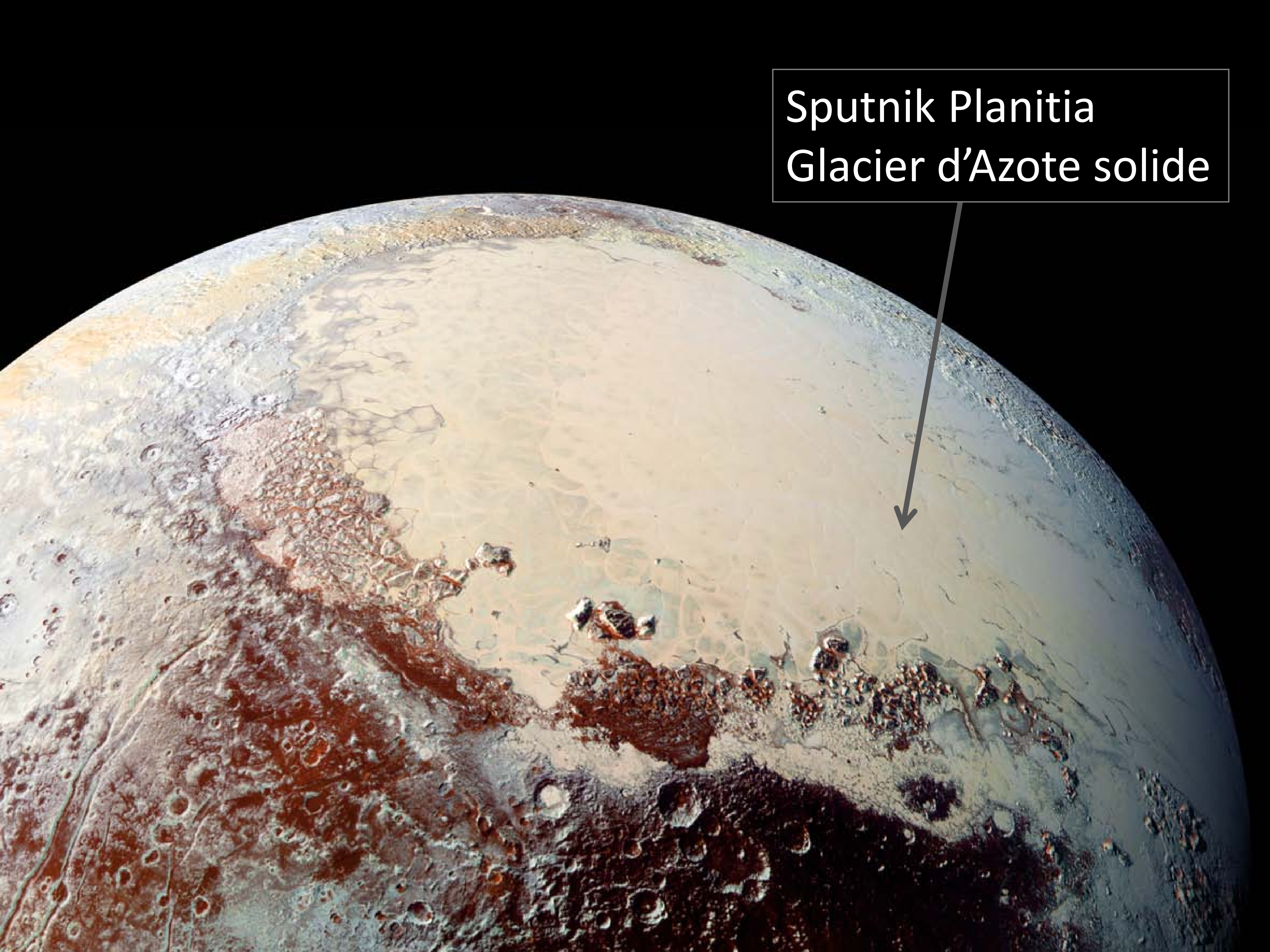


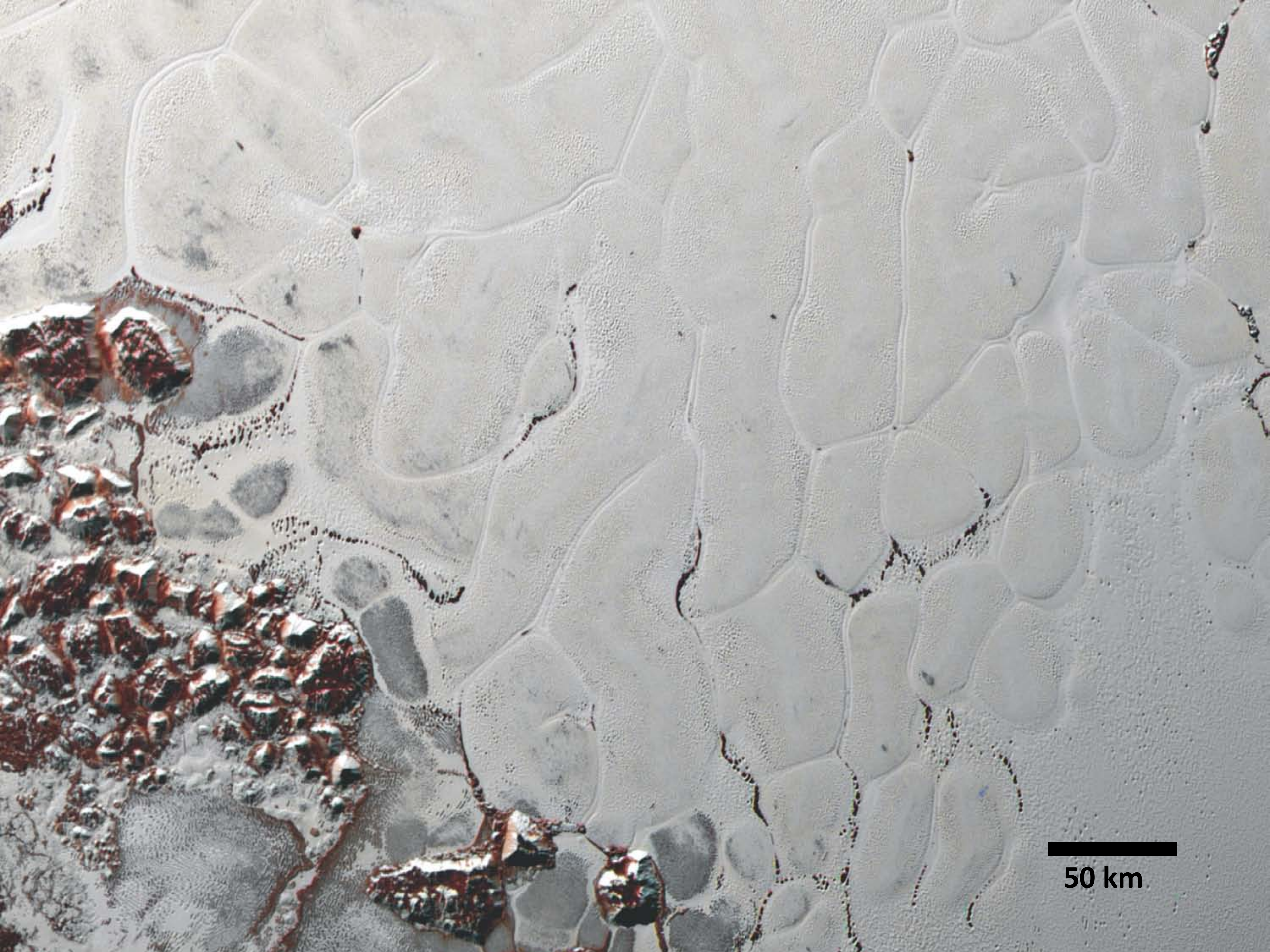



False Color



False color


Sputnik Planitia
Glacier d’Azote solide

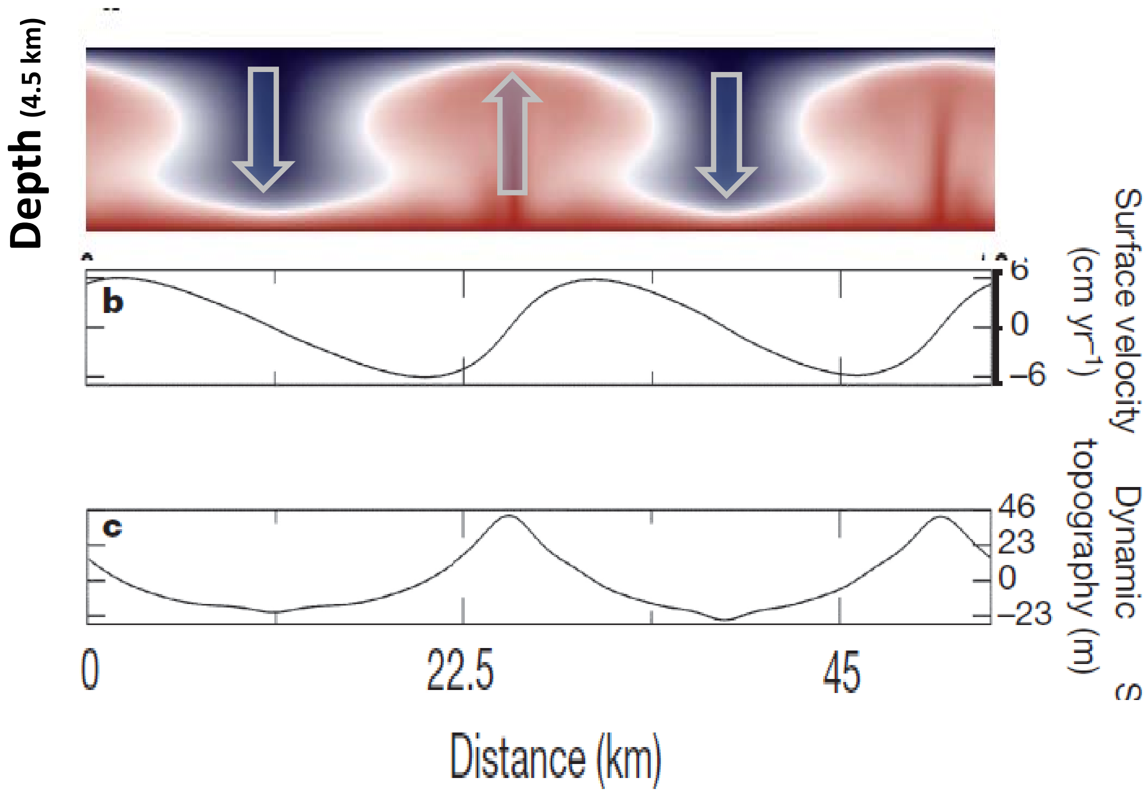

50 km

Convection in Sputnik Planitia Nitrogen Glacier

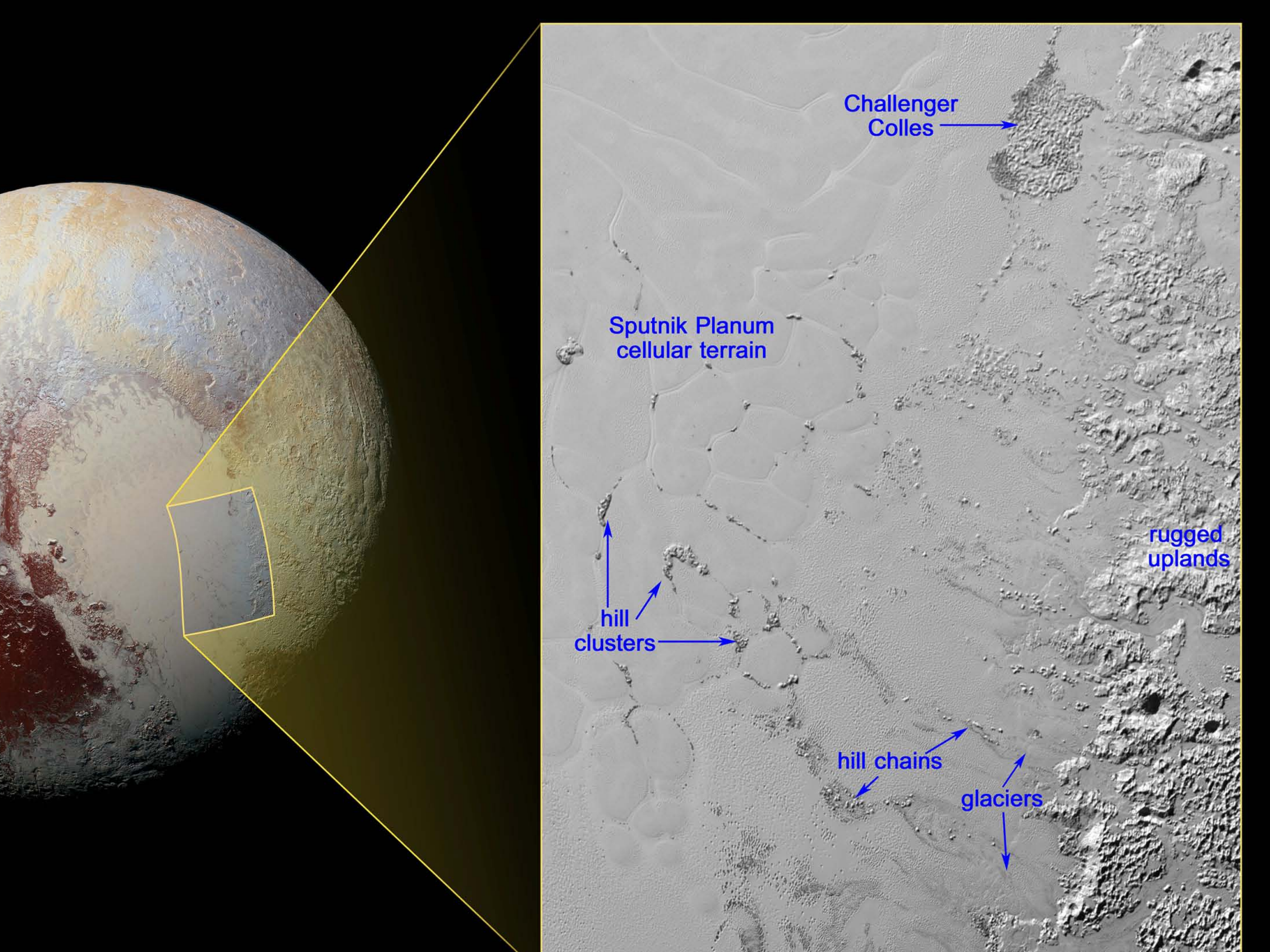
Numerical simulations of a **4.5 km deep** N_2 ice layer with realistic interior heat flow at the bottom ($\Delta T = 20$ K)

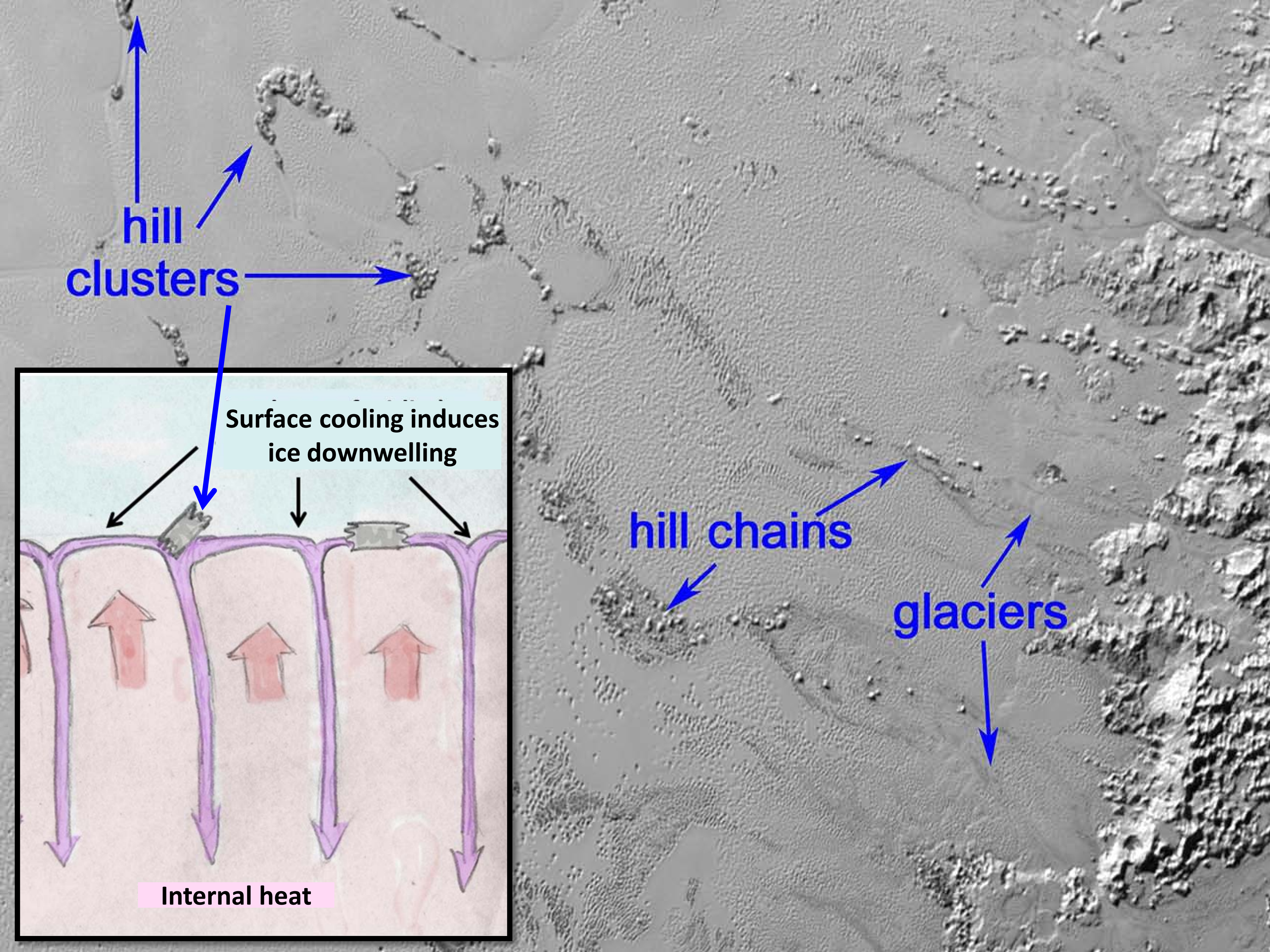
⇨ "sluggish lid regime" convection

McKinnon et al. (Nature, 2016)

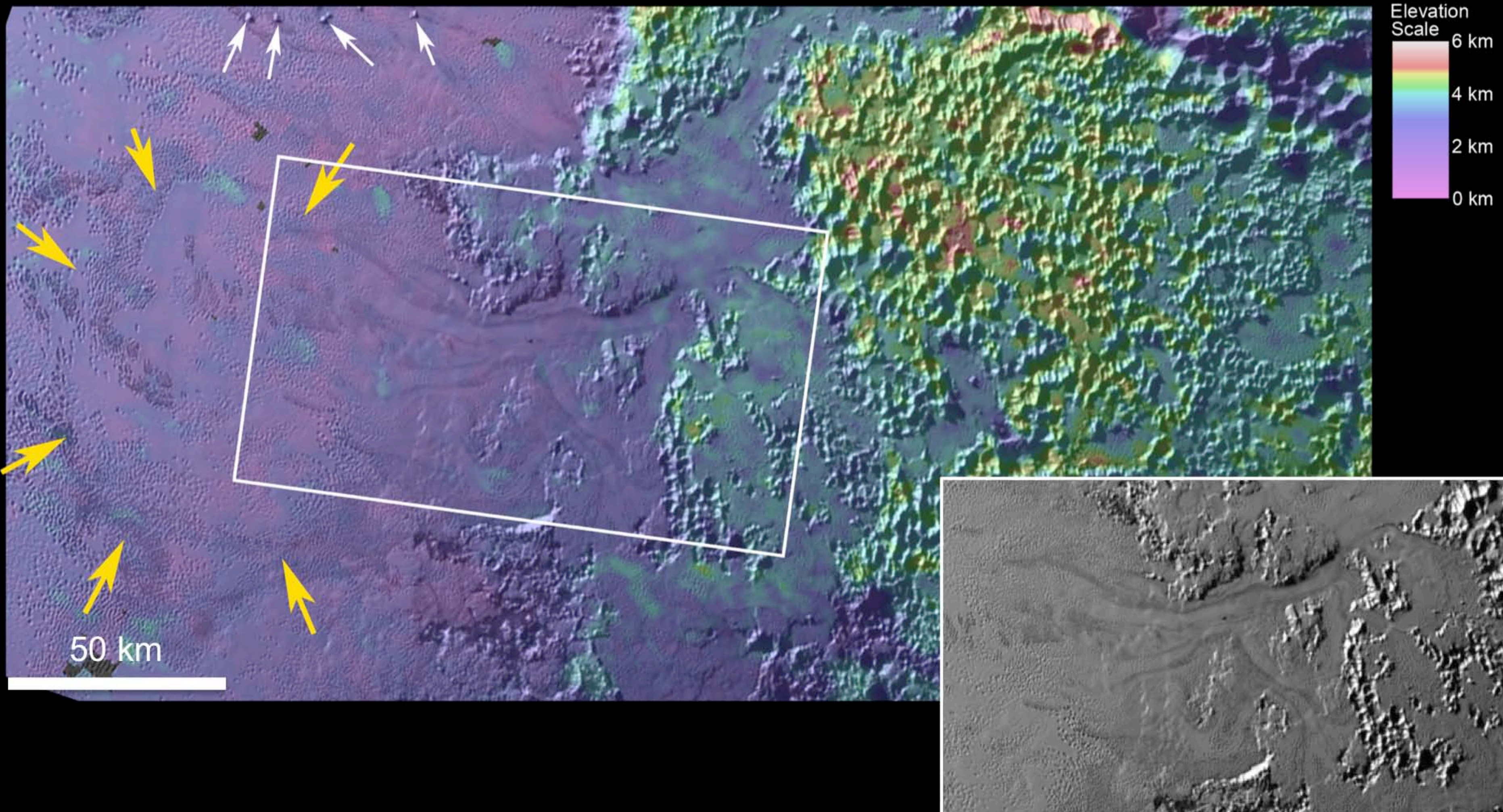


50 km

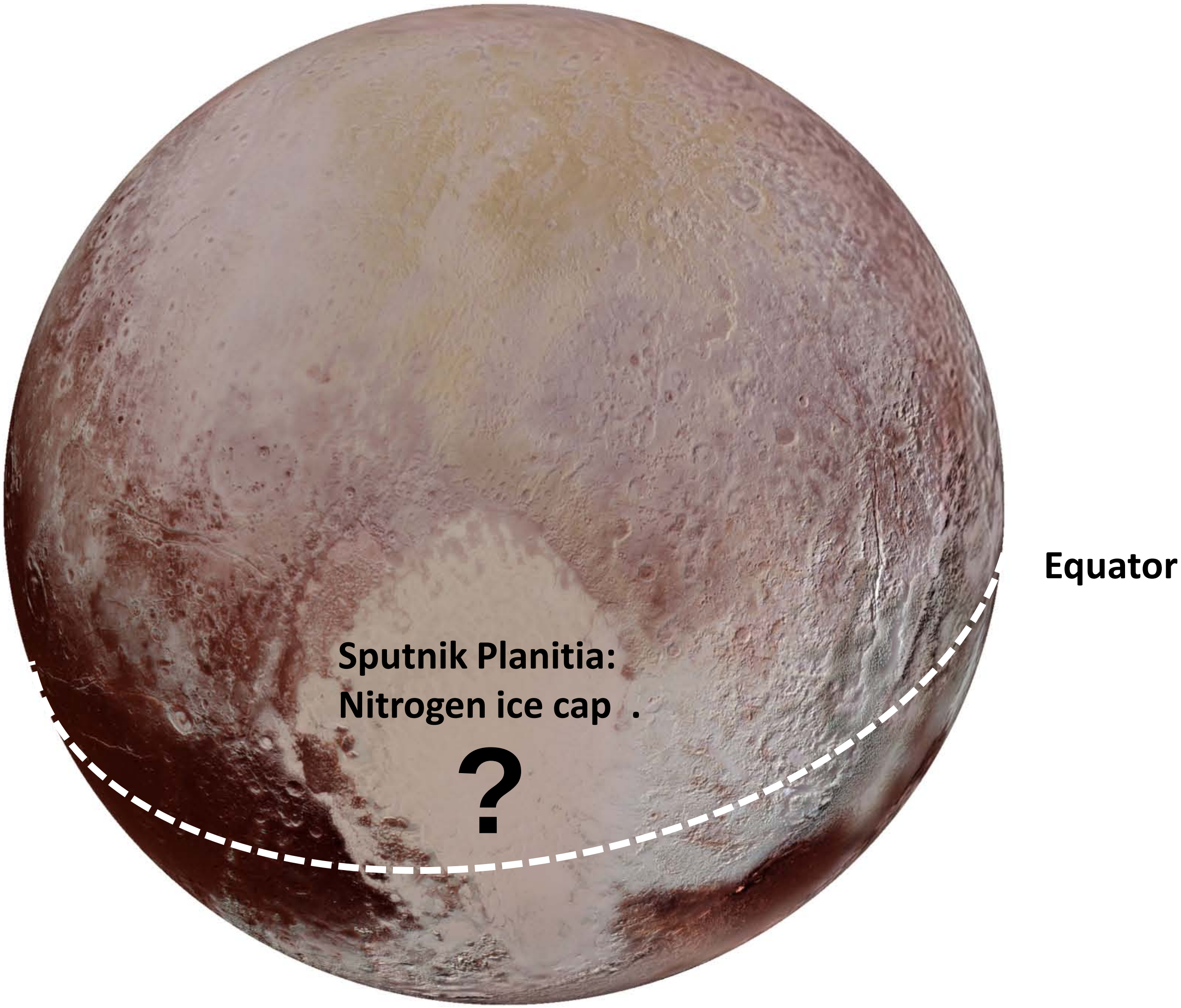

Challenger
Colles
Sputnik Planum
cellular terrain
rugged
uplands
hill
clusters
hill chains
glaciers


hill
clusters
hill chains
glaciers
Surface cooling induces
ice downwelling
Internal heat

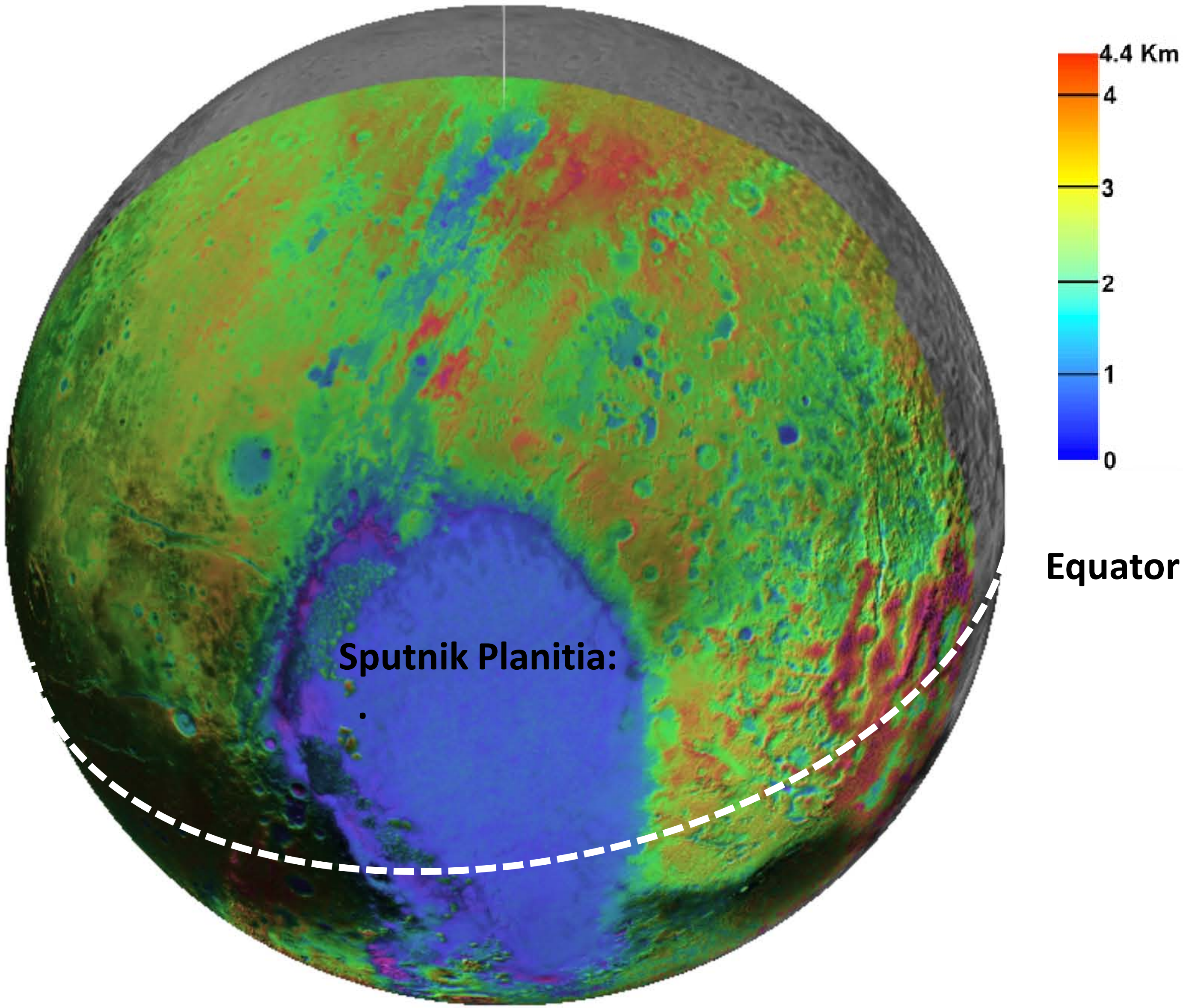
Glacial flow into Sputnik Planitia



Unambiguous evidence of massive, recent downslope glacial flow


Equator
Sputnik Planitia:
Nitrogen ice cap .
?

Stereo Topography



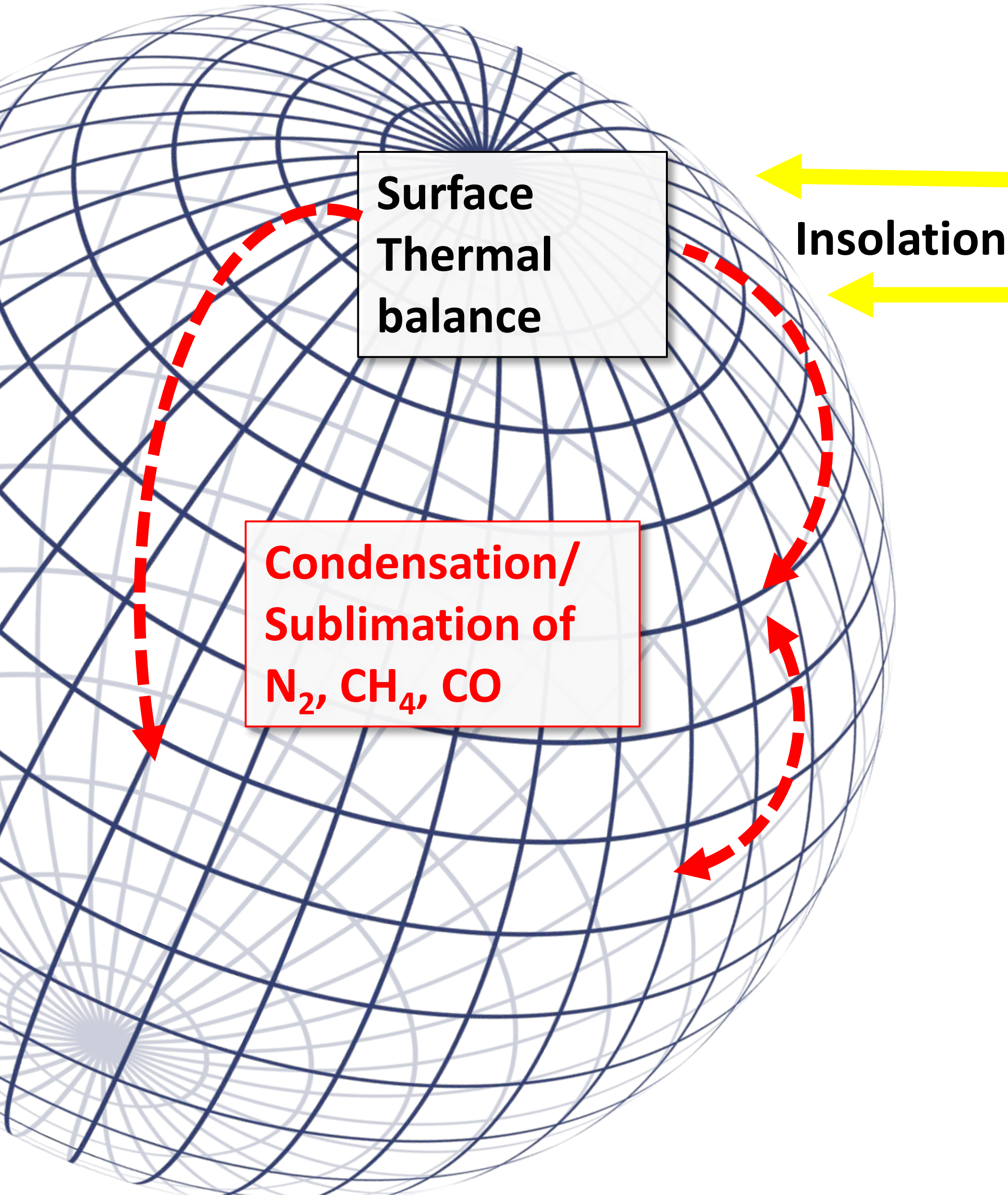
Numerical modeling of temperatures and ices on Pluto

(Bertrand and Forget, Nature 2016)

Tanguy Bertrand
Doctorant au LMD

Numerical modeling of temperatures and ices on Pluto

(Bertrand and Forget, Nature 2016)



Tanguy Bertrand Doctorant au LMD

First 10,000 years of the reference simulation

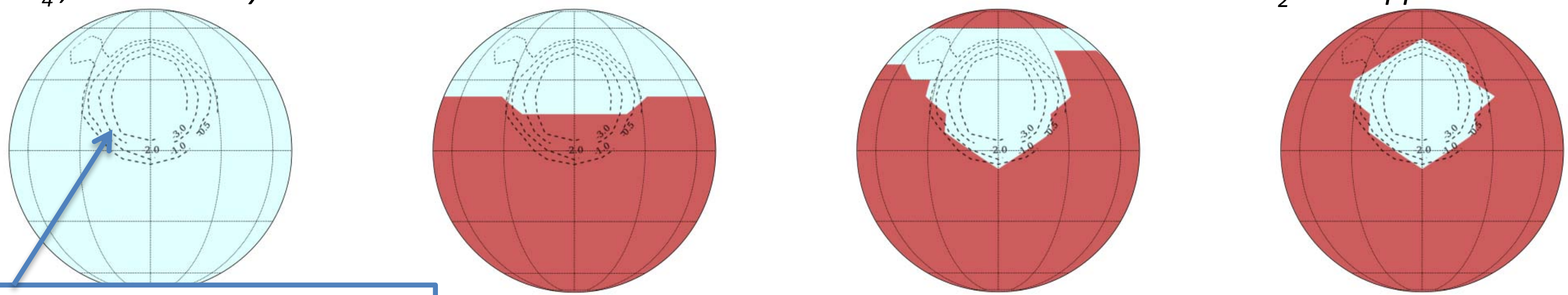
(Bertrand and Forget, Nature 2016)

Initial distribution — *N_2, CH_4, CO ices everywhere*

After 250 years

After 4000 years

After 10000 years — *All N_2 ice trapped in the basin*



« Sputnik Planum »-like basin
(3 km deep)

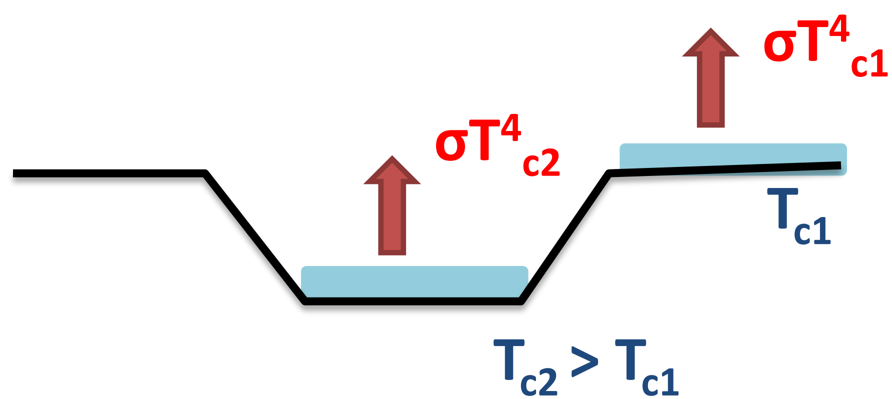
Pure CH_4

$N_2 + CH_4 + CO$

Ice-free

Condensation rate:

$$\frac{dM}{dt} = \frac{\sigma T_c{}^4}{L}$$

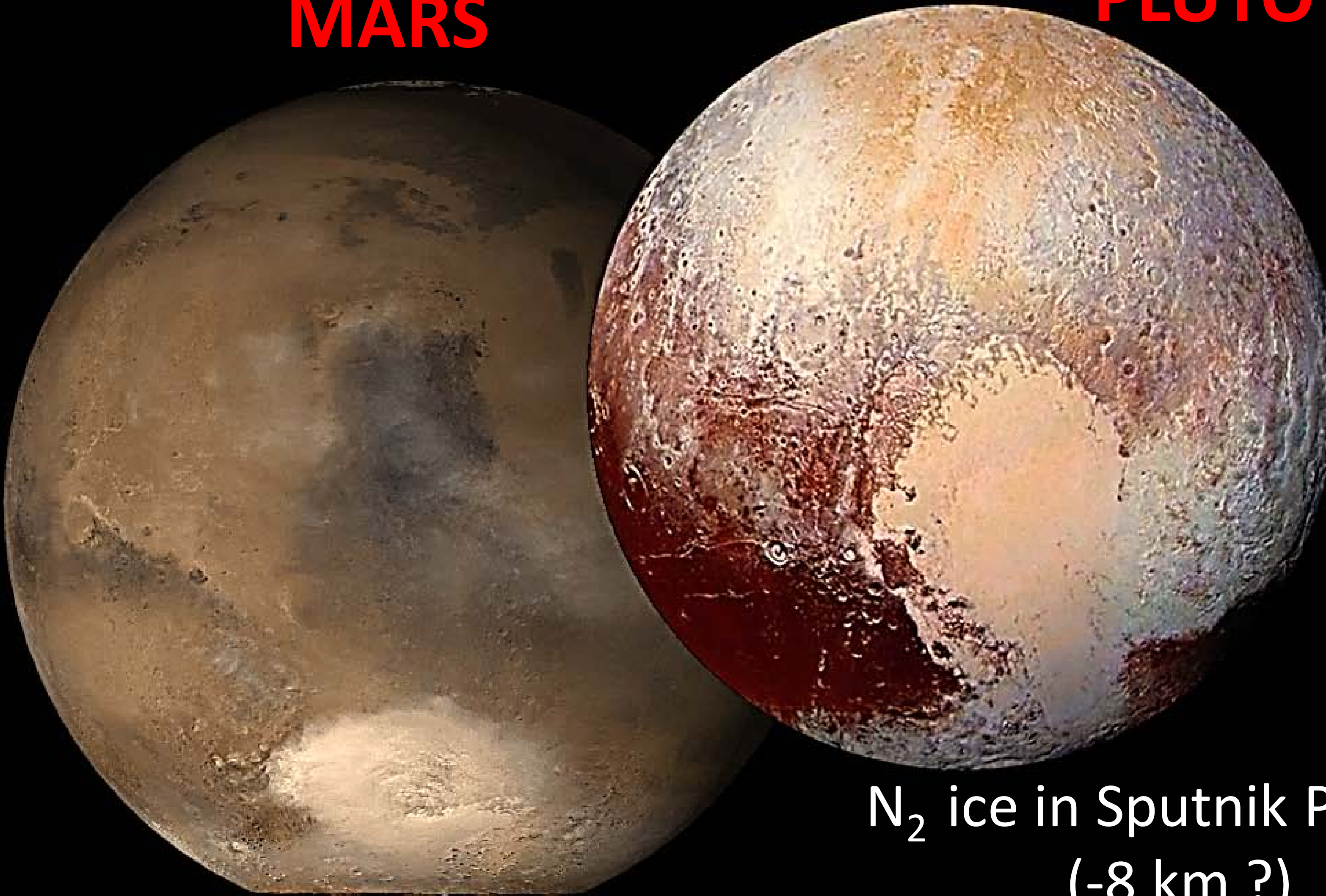


N_2 ice tends to stabilize in the crater because of the higher pressure

⇨ warmer N2 frost point ⇨ stronger Thermal cooling

⇨ Increased condensation rate

MARS **PLUTO**



N_2 ice in Sputnik Planitia
(-8 km ?)

CO_2 ice in Hellas
crater (-8 km)

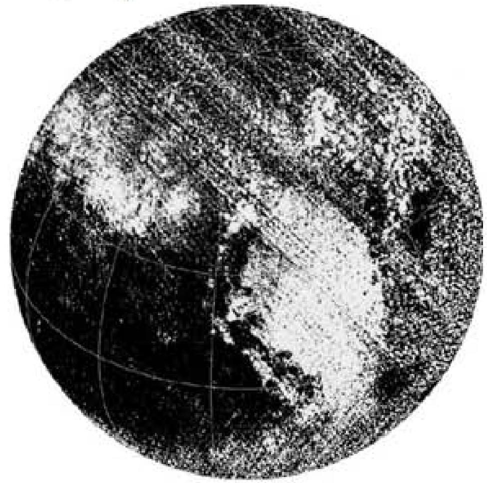
Pluton in 2015

(Bertrand and Forget, Nature 2016)

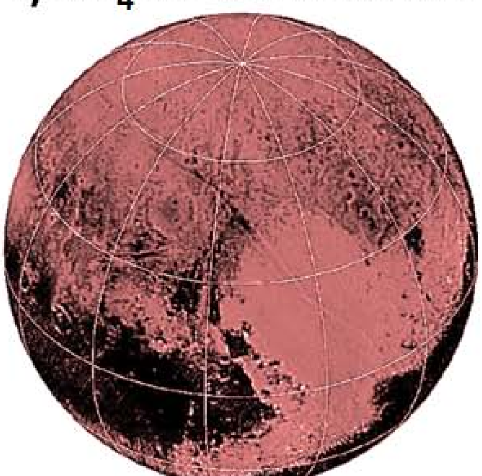
(Grundy et al., Science 2016)

a) Pluto by New Horizons

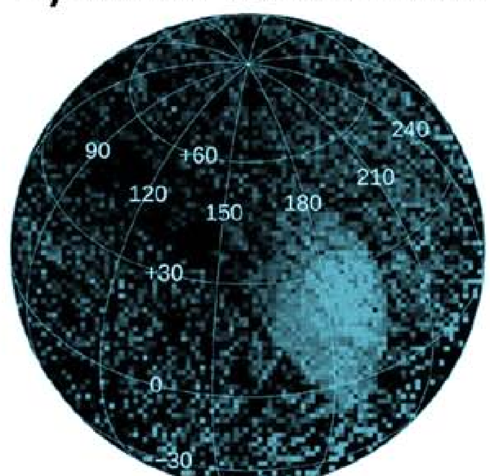
b) N_2 ice observation



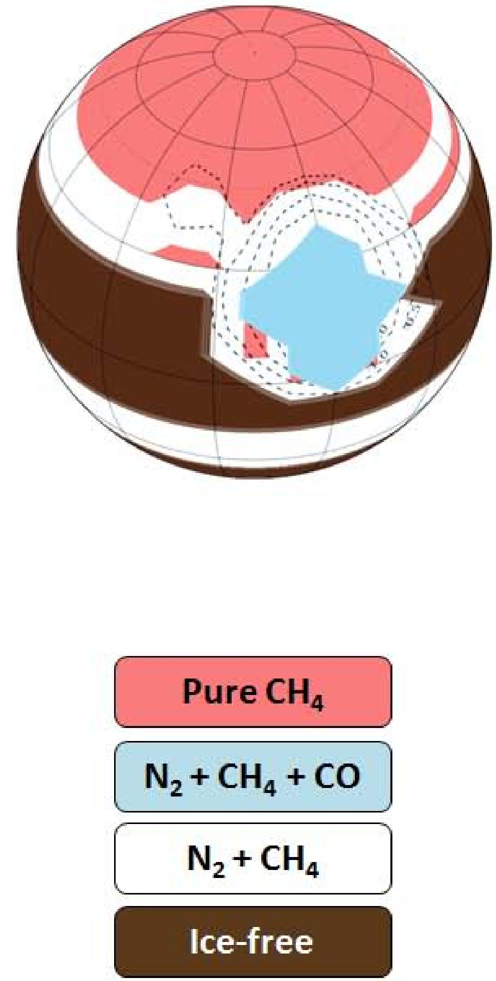
c) CH_4 ice observation



d) CO ice observation

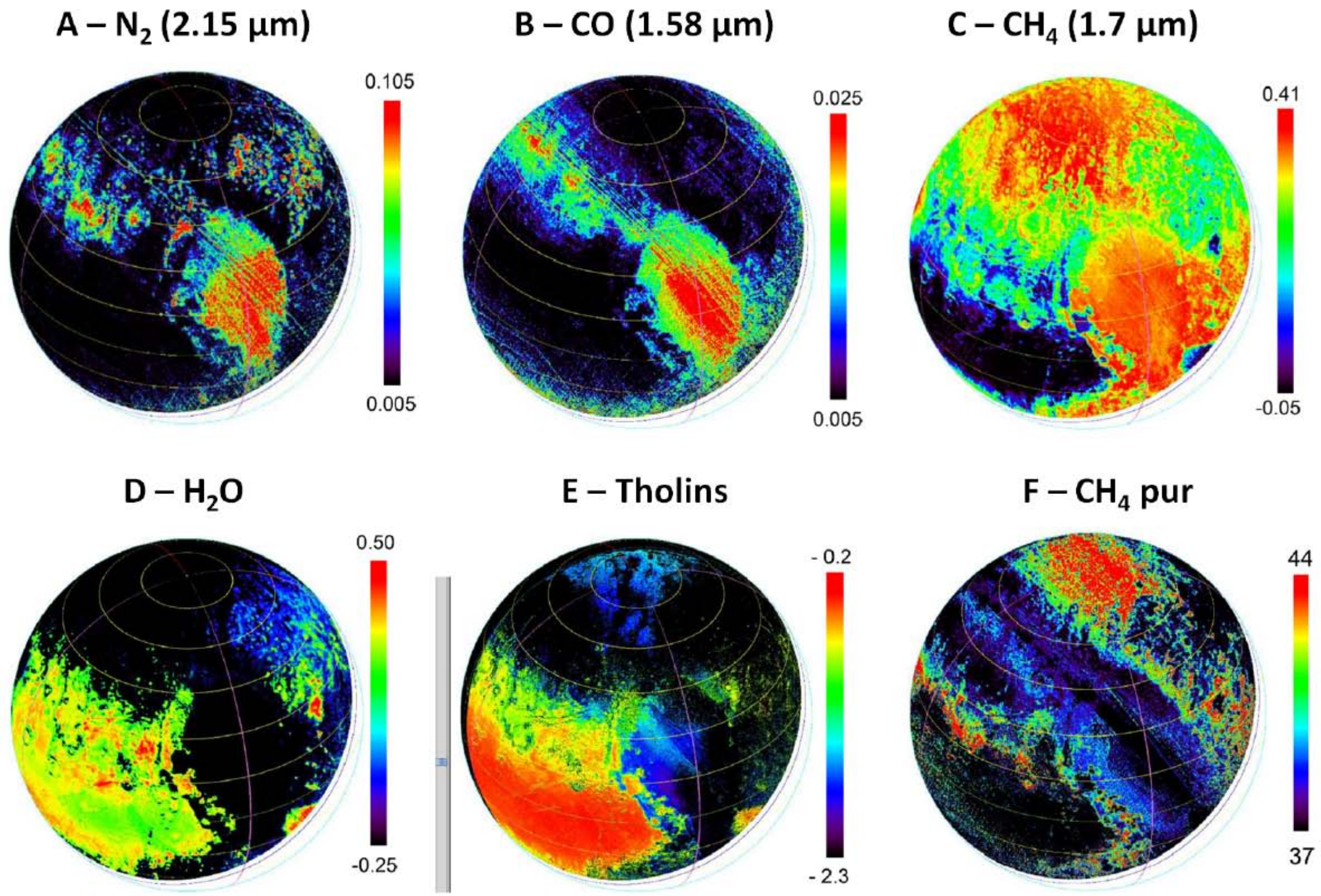


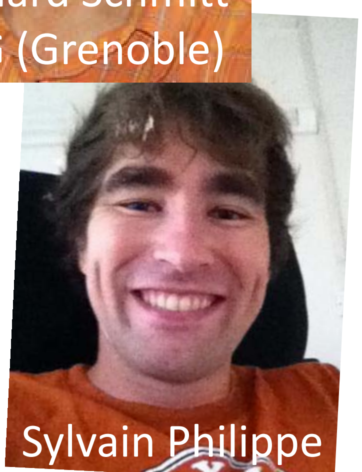
e) Model



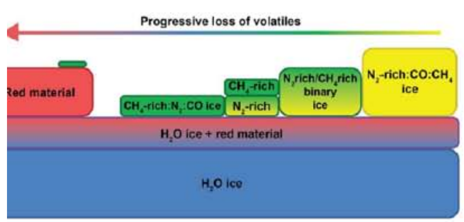
Physical state and distribution of materials at the surface of Pluto from New Horizons LEISA imaging spectrometer

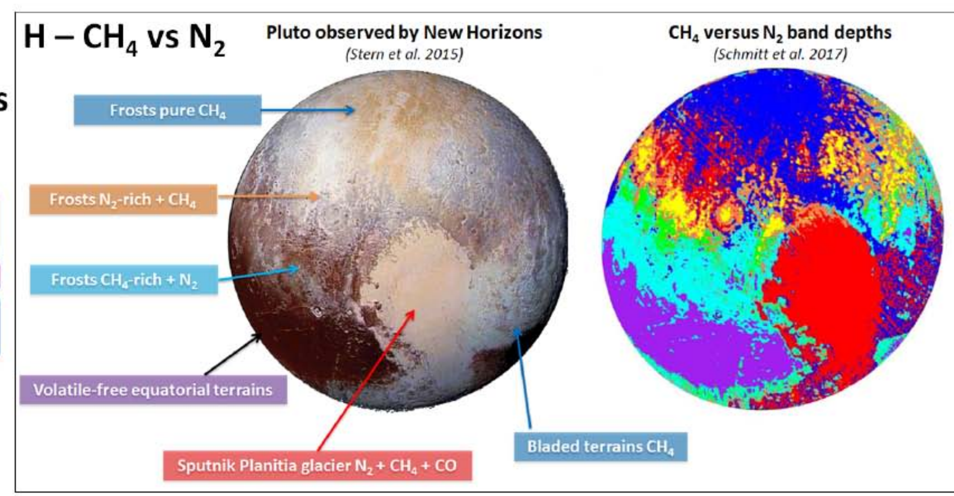
Schmitt et al. Icarus 2017



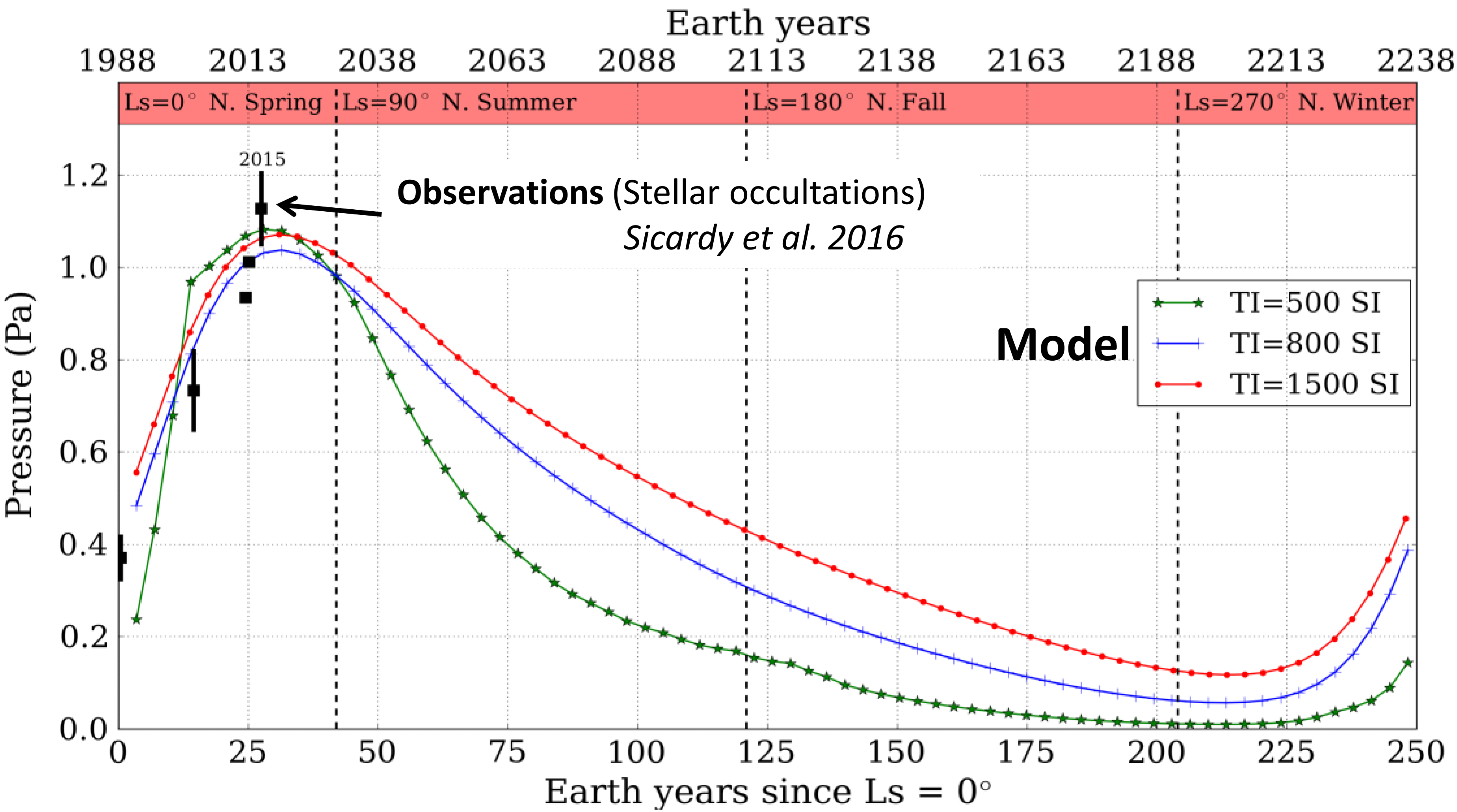


Evolution des glaces volatiles

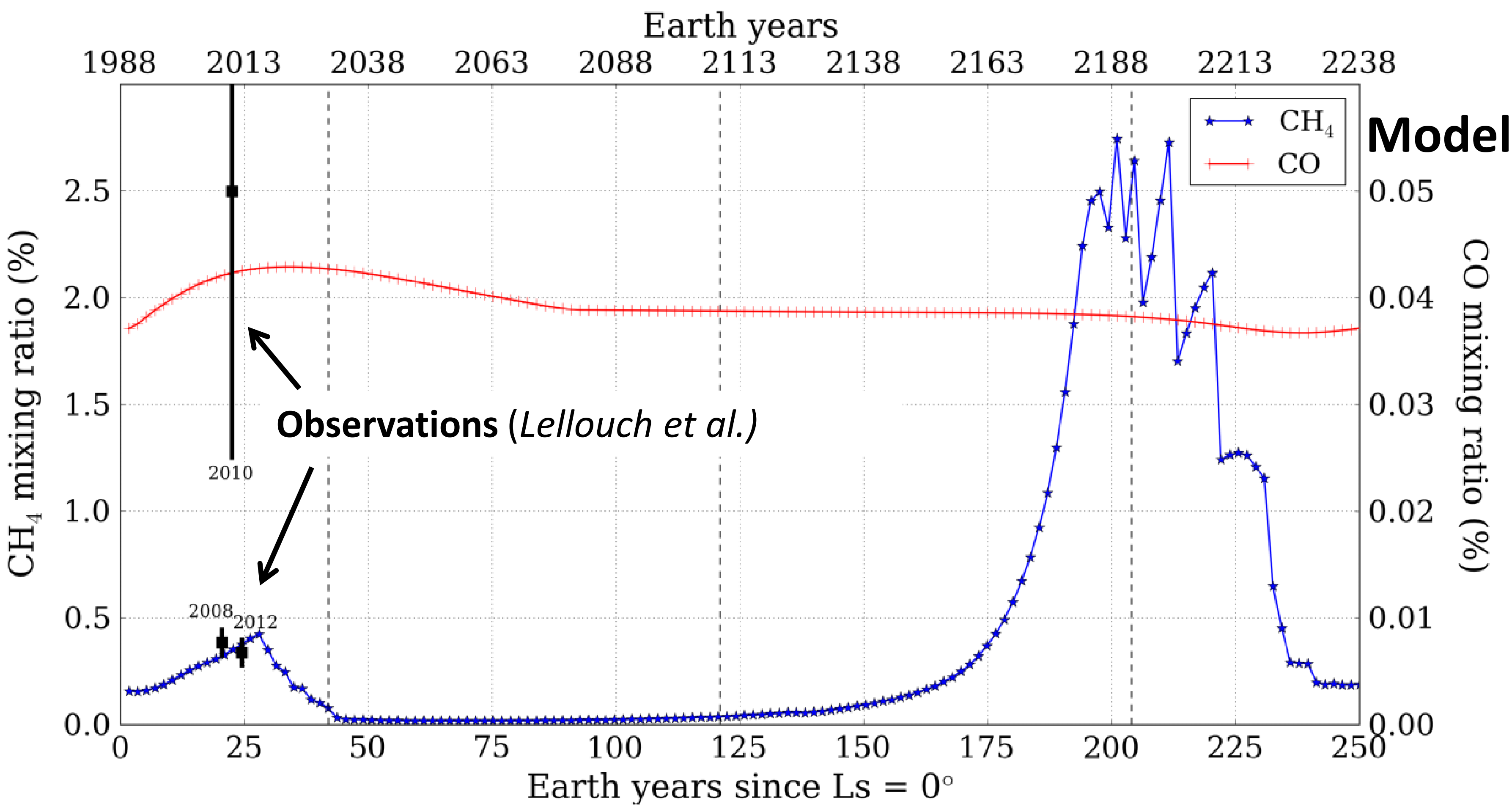




Modeled Evolution of Surface pressure

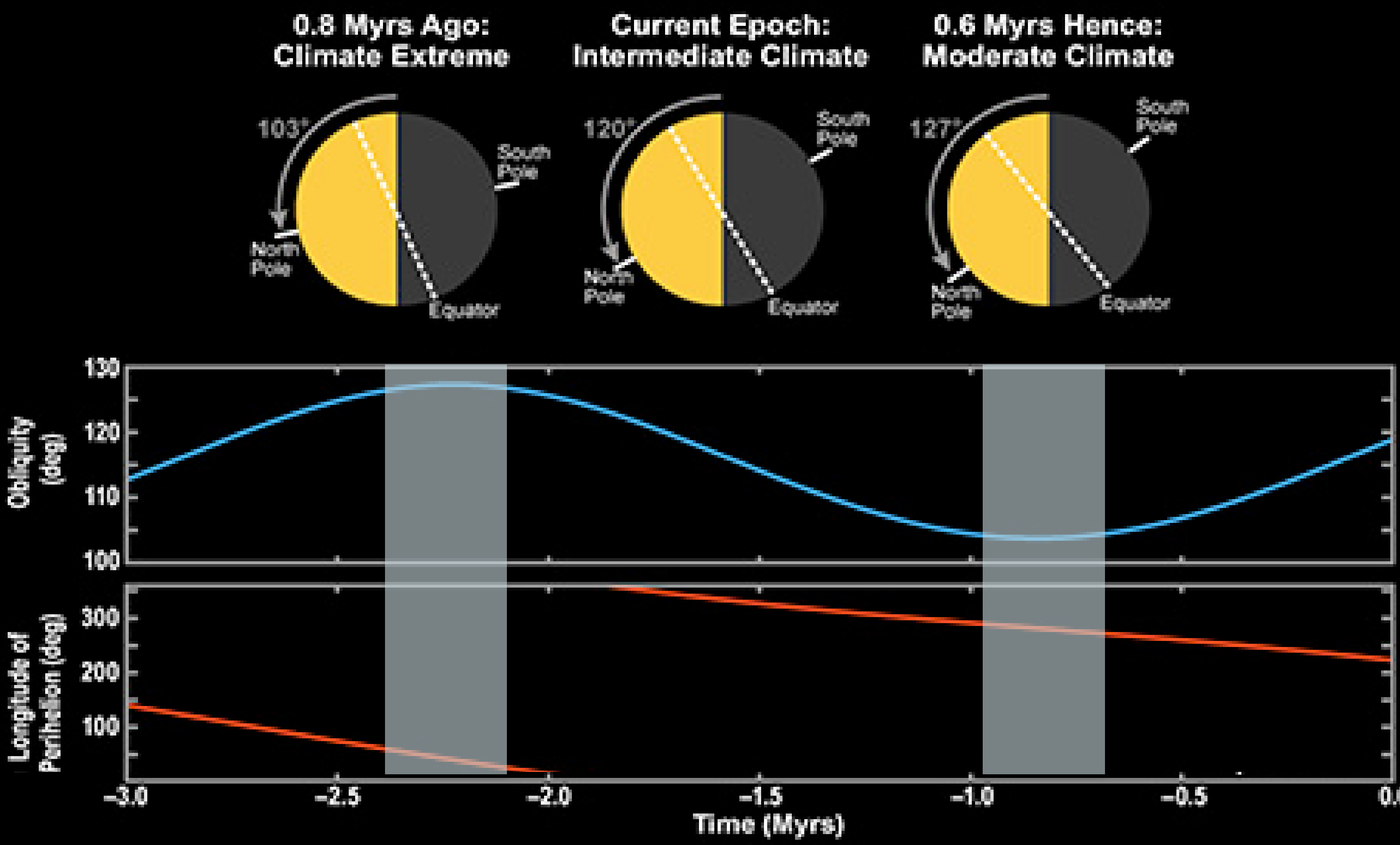


Atmospheric mixing ratio of CO and methane



Paleoclimates of Pluto

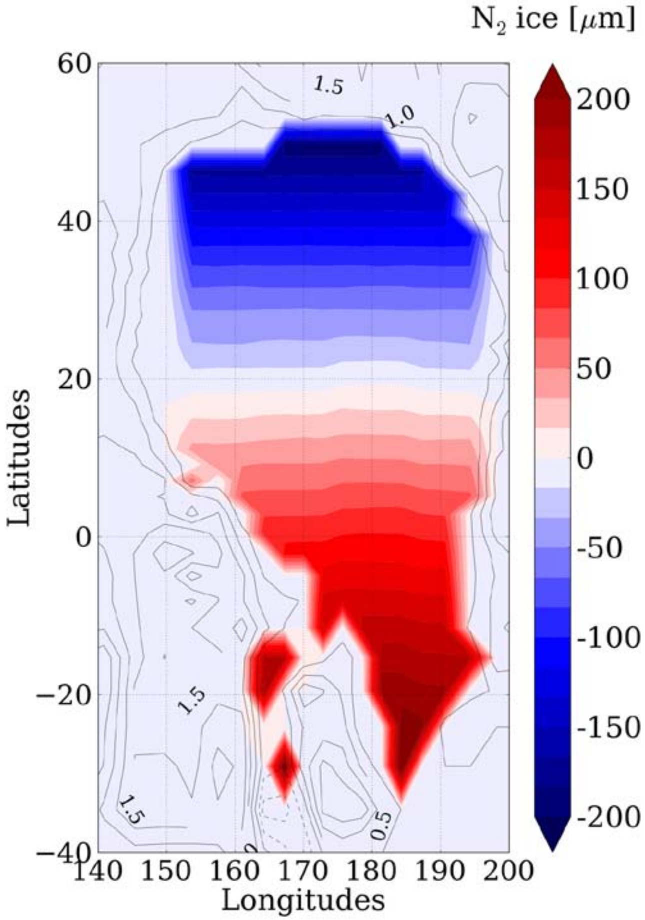
Changes of obliquity and longitude of perihelion over 3 millions years

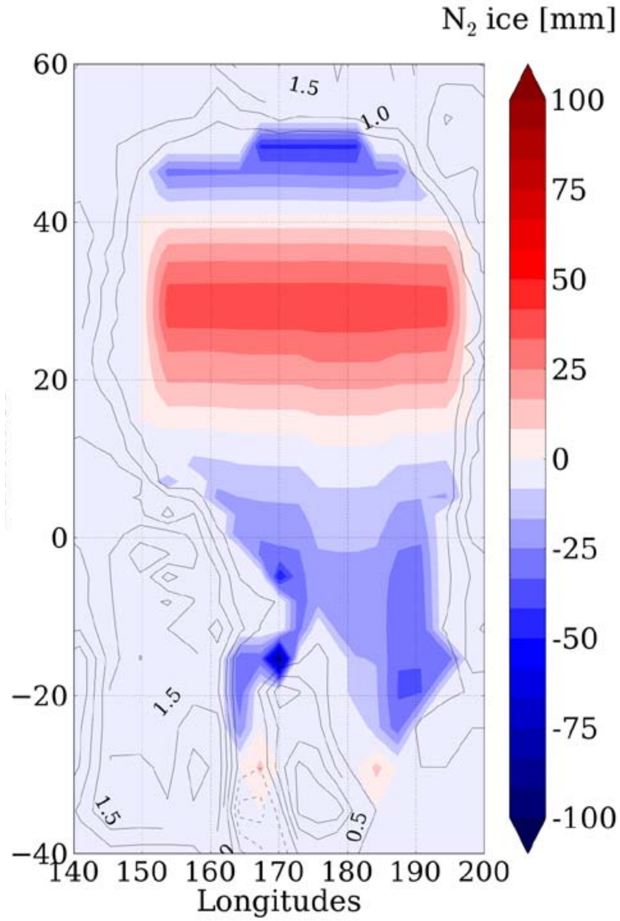


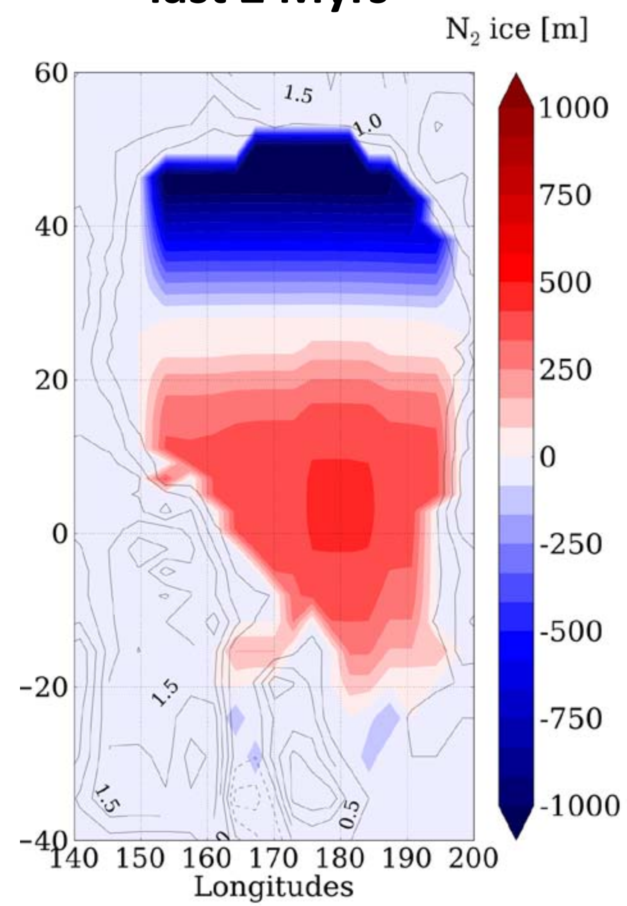
Earle & Binzel (2015), Dobrovolskis et al. (1997), and Dobrovolskis & Harris (1983)

Modeled Net Budget of N_2 ice in Sputnik Planitia

(Bertrand et al. 2017)





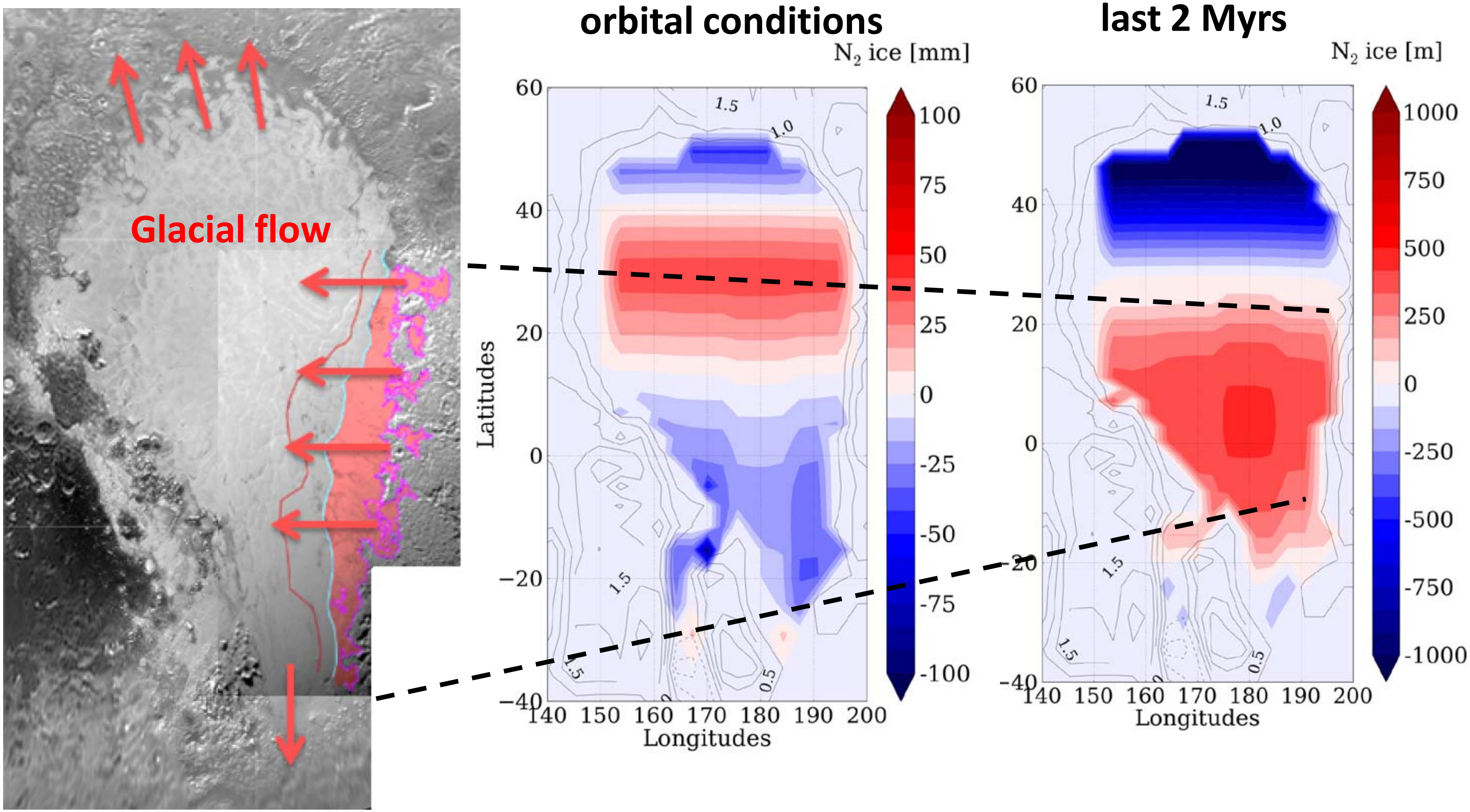


Modeled Net Budget of N_2 ice in Sputnik Planitia

(Bertrand et al. 2017)

during one Pluto year in current orbital conditions

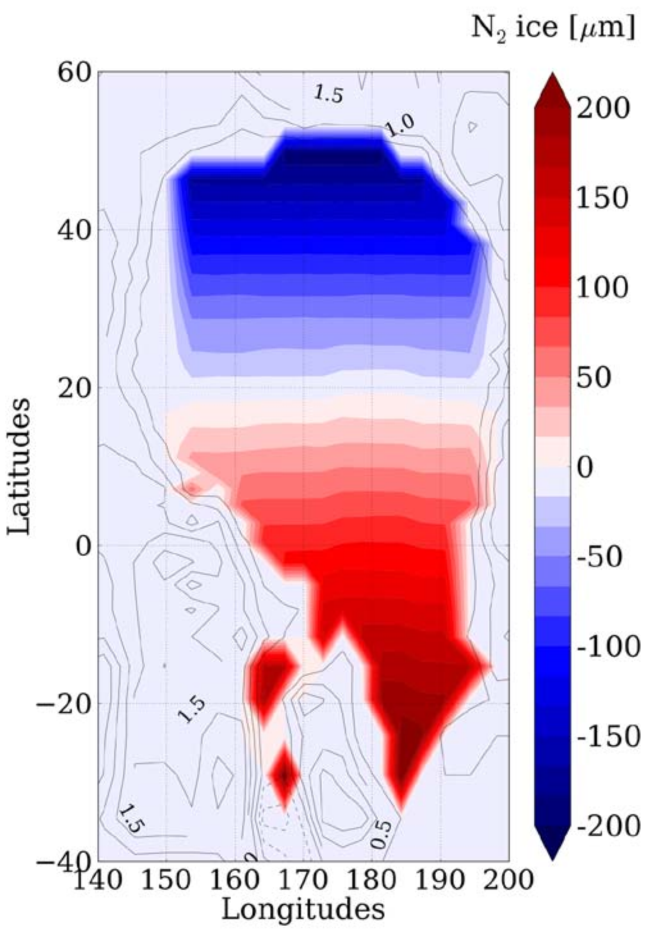
during the last 2 Myrs



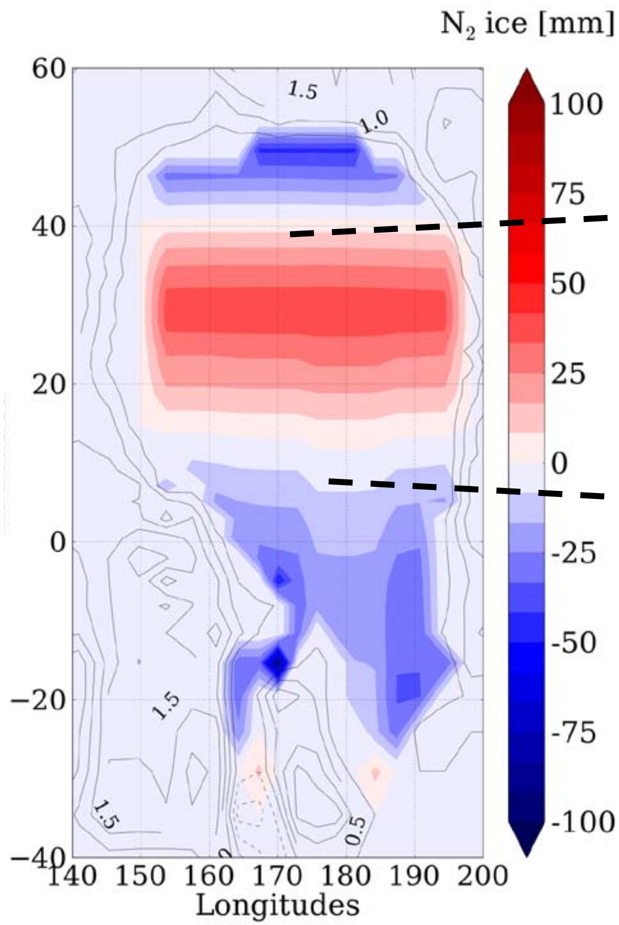
Modeled Net Budget of N_2 ice in Sputnik Planitia

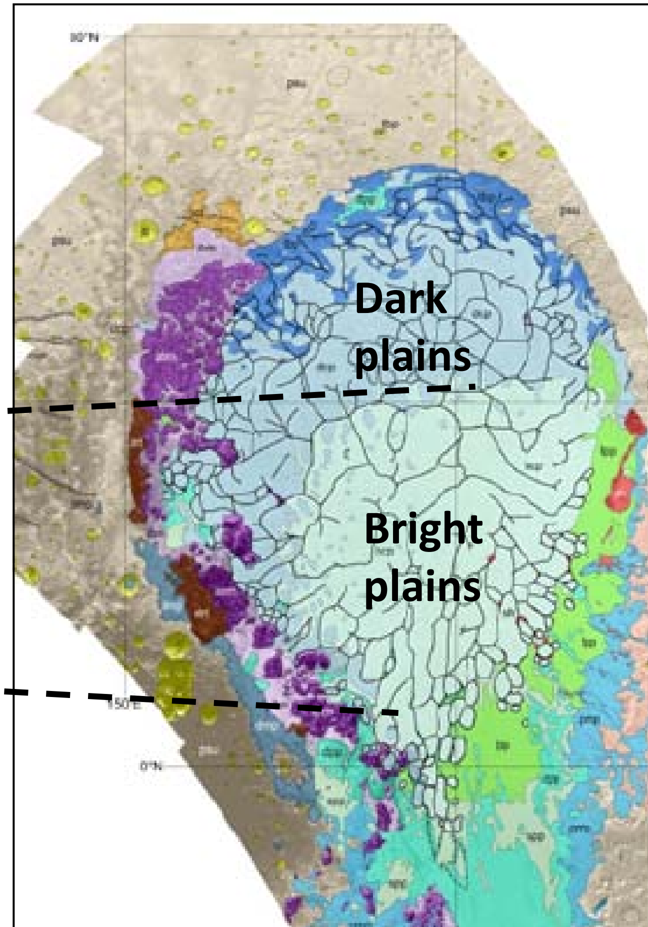
(Bertrand et al. 2017)

during one Pluto day



during one Pluto year in current orbital conditions

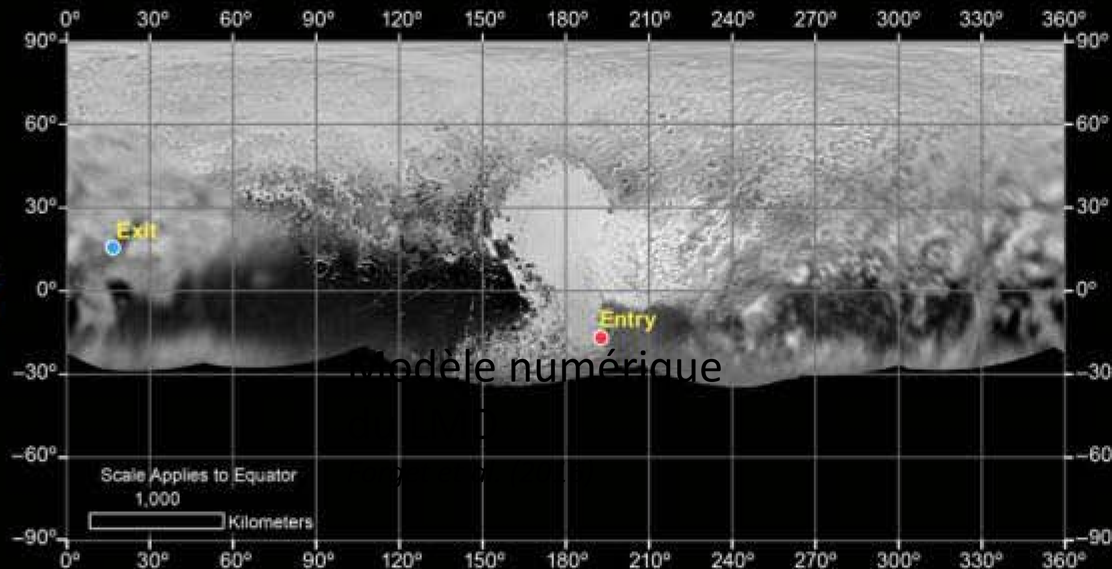




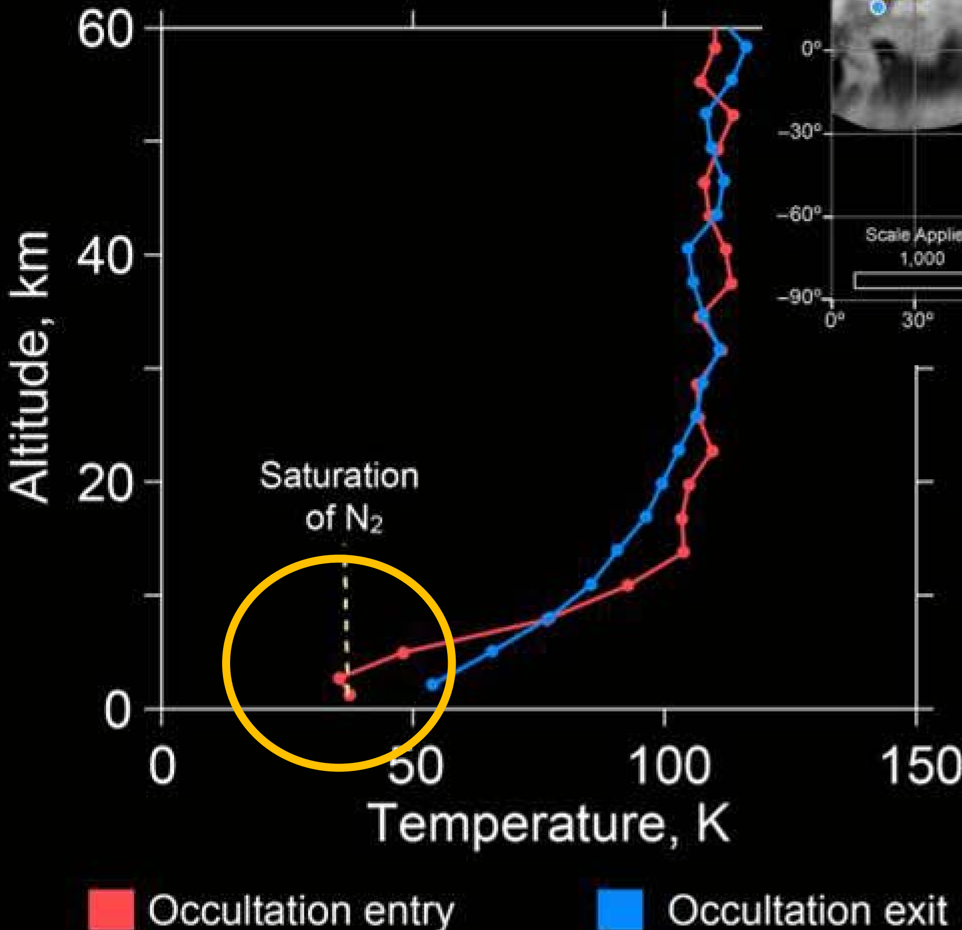
Geological map of the Sputnik Planitia region (*White et al, 2017*)

An atmosphere on Pluto ?

Mesure de la temperature par occultation Radio



Modèle numérique



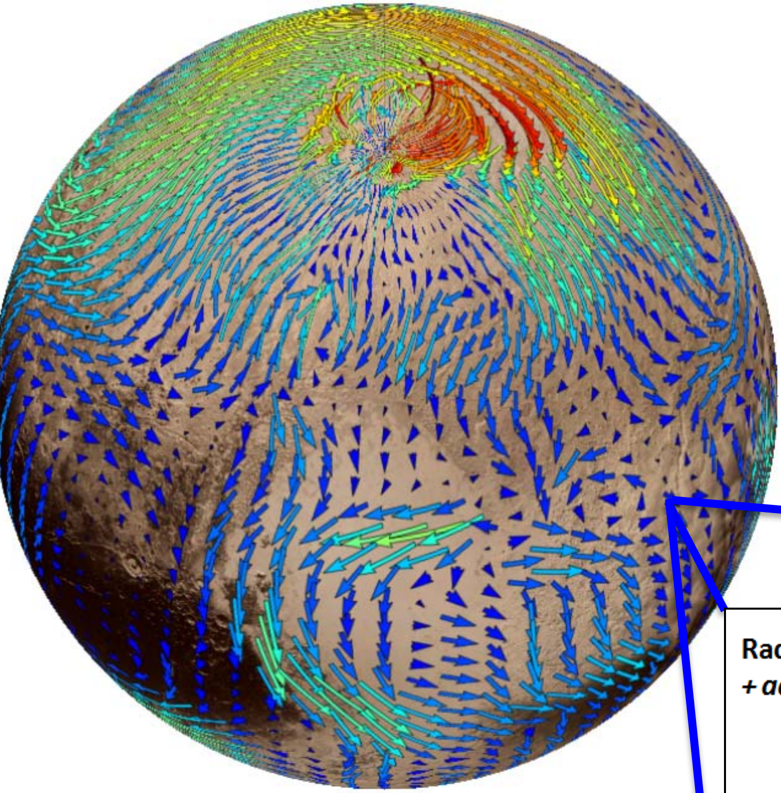
Different temperatures at entry and exit occultations

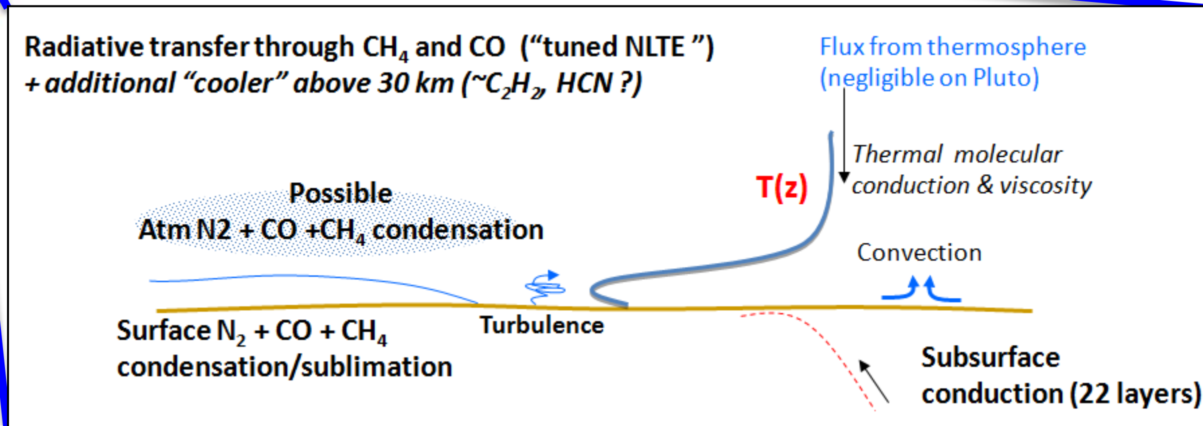
Pluto atmosphere General Circulation Model (GCM)

(LMD, Paris)

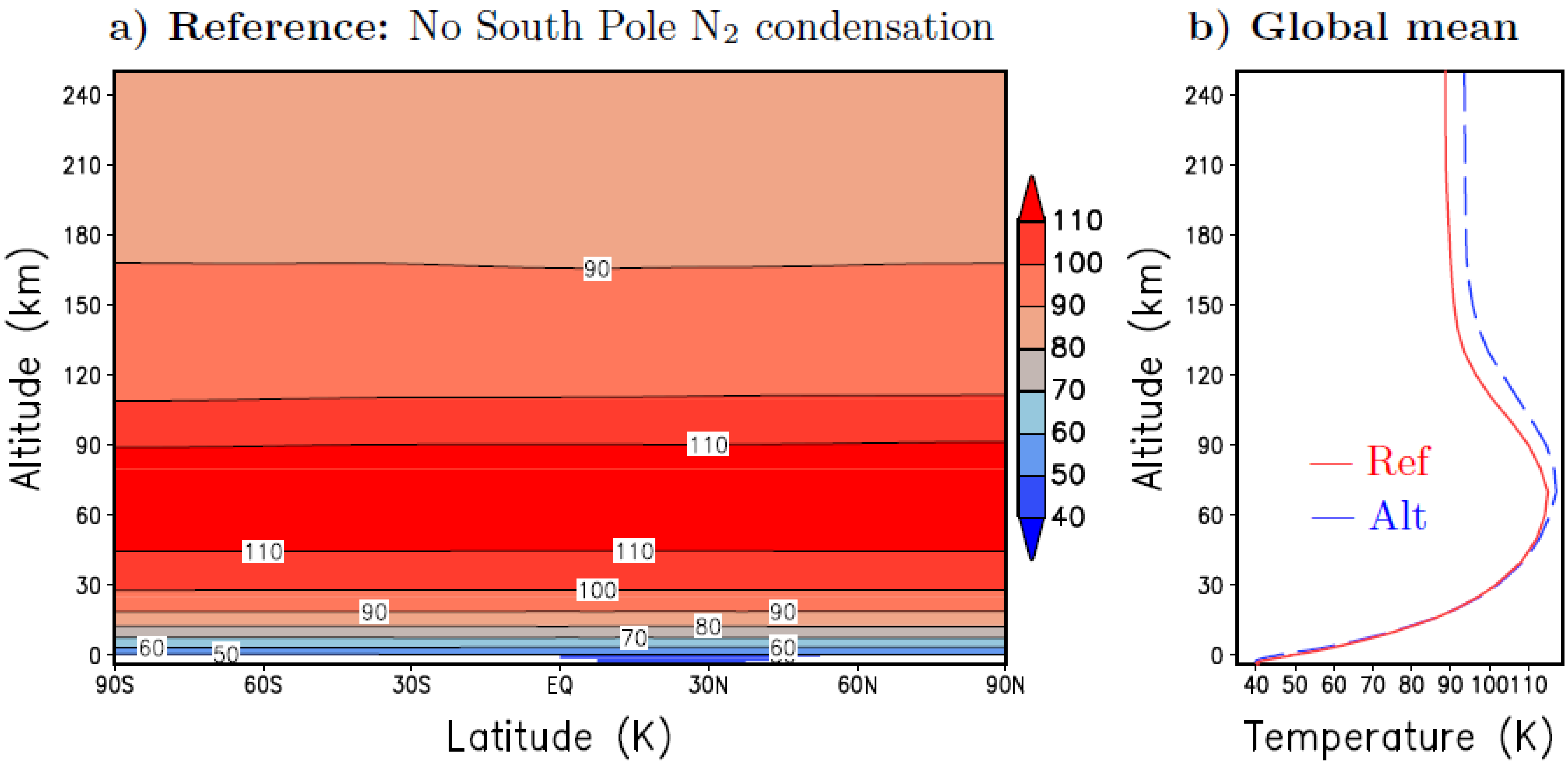
Tanguy Bertrand
Doctorant au LMD

Mélanie Vangvichith
(These en2013)



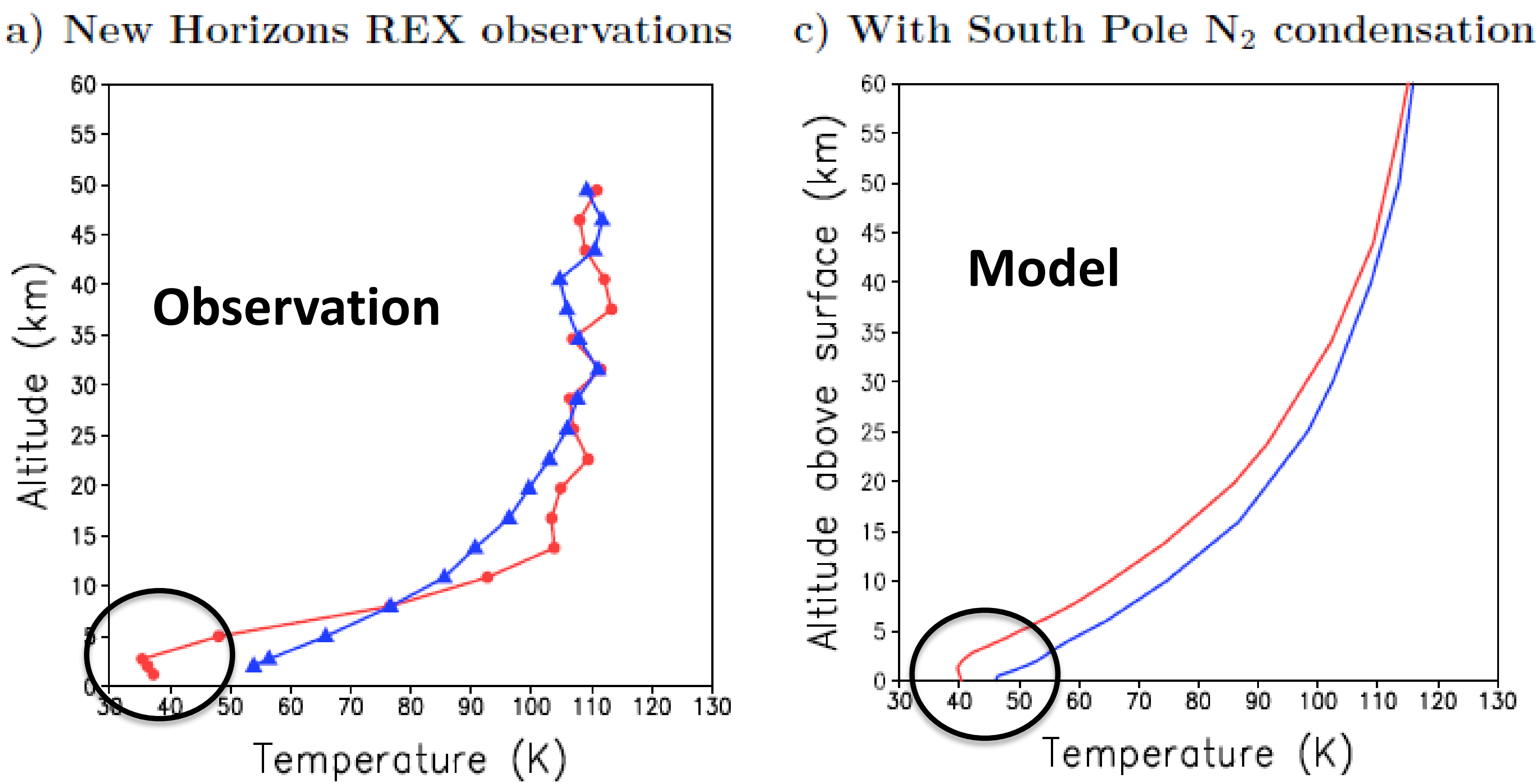


Zonal Mean temperature



Comparison with REX observations

(Hinson et al, Gladstone et al., 2016,.)

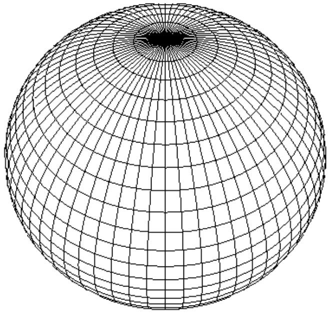


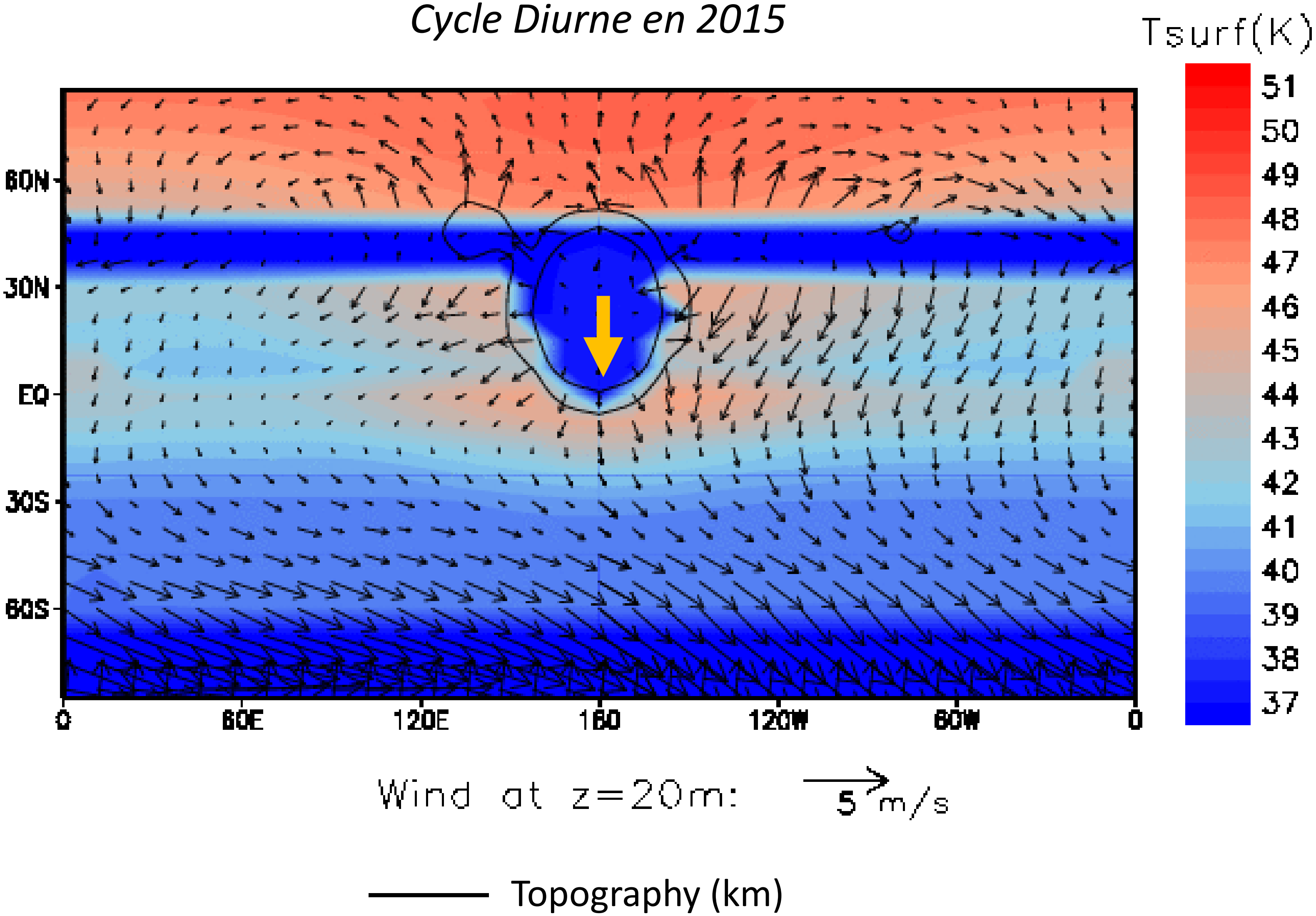
Ingress: 193.5◦E, 17.0◦S and Local time 16:31 (7.5◦N in the GCM)

Egress: 15.7◦E, 15.1◦N and Local time 04:42

Modélisation numérique de Pluto au LMD
Temperature et vents à la surface

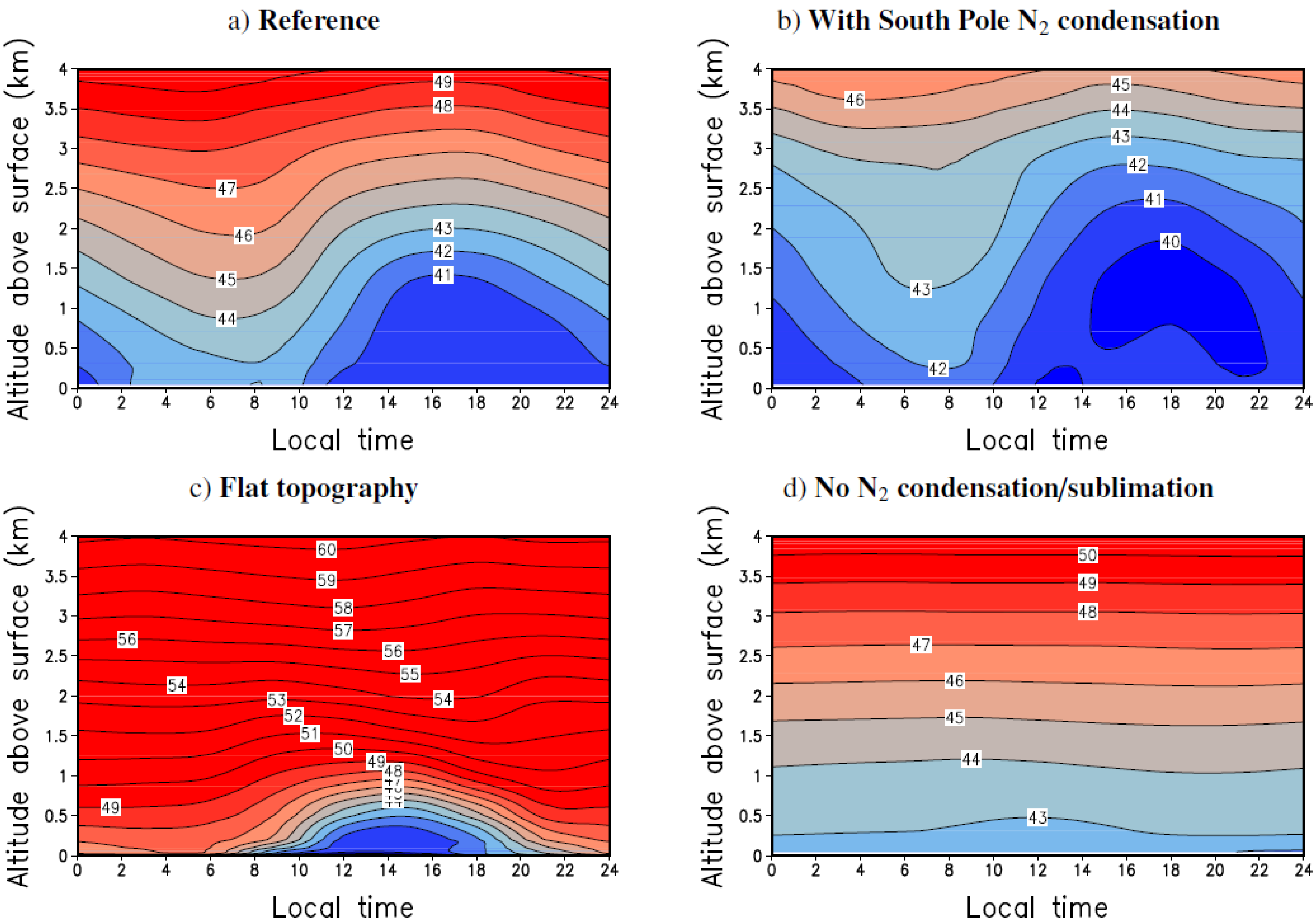
Cycle Diurne en 2015





The low level inversion is induced by N_2 sublimation + topography

T Diurnal cycle in modeled Sputnik Planum (7.5°N 180°E) *(see also Hinson 2015)*



A summary of possible circulations

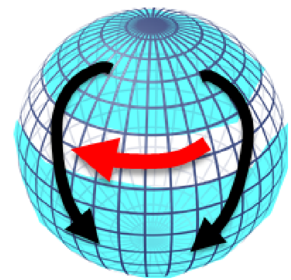
(Forget et al. 2017)

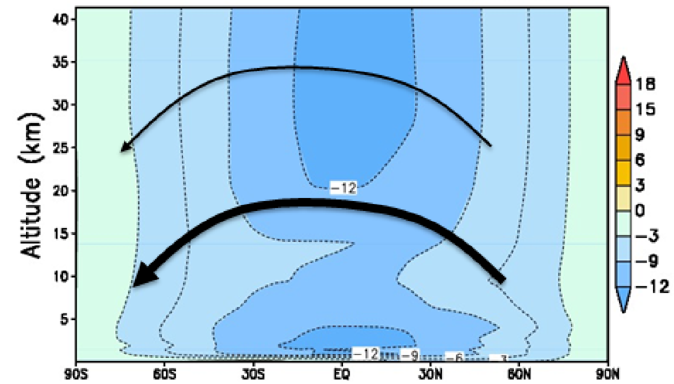
Cas de simulation | **Moyenne zonale des vents zonaux (m/s)**

Flux intense de condensation N_2

(Toigo et al. 2015)

Rétro-superrottation

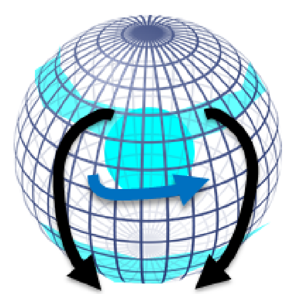


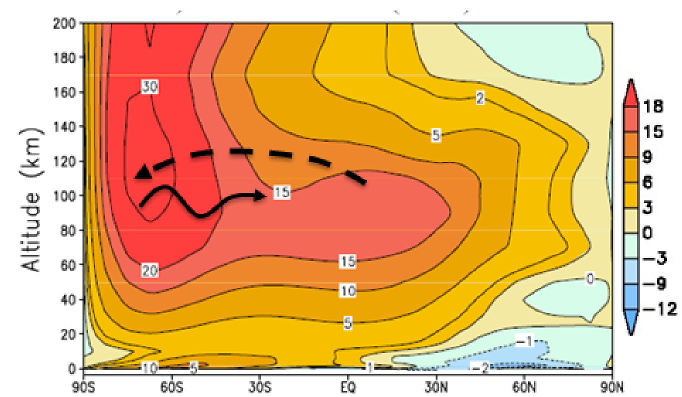


Flux modéré de condensation N_2

(Simulation alternative)

Superrotation

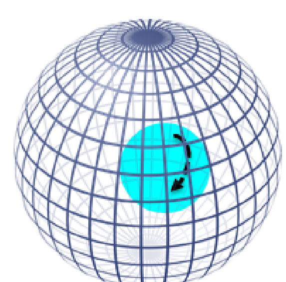


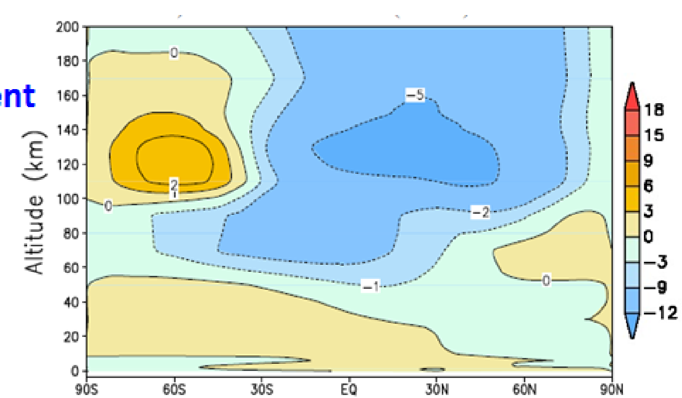


Pas de flux de condensation

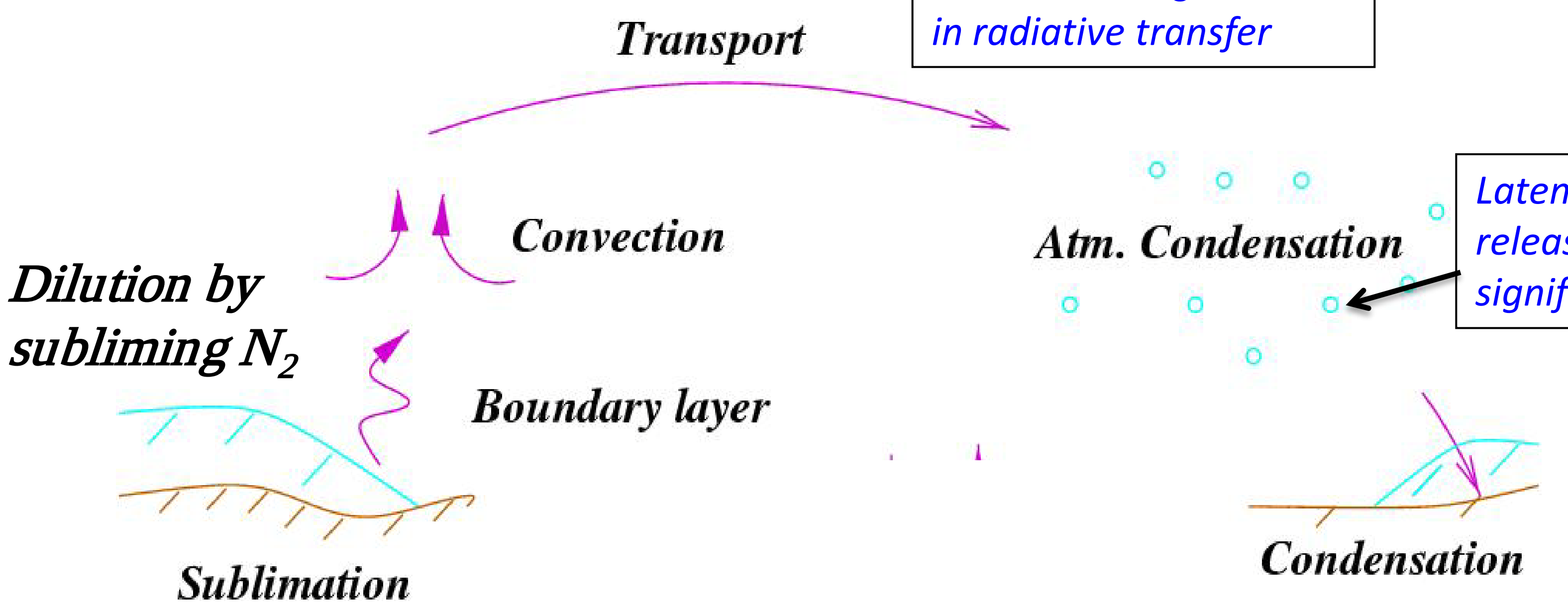
(Simulation de référence)

Faibles vents induits thermiquement





Modelling the Methane cycle



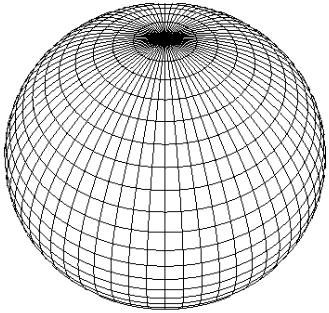
Modeled CH4 gas used in radiative transfer

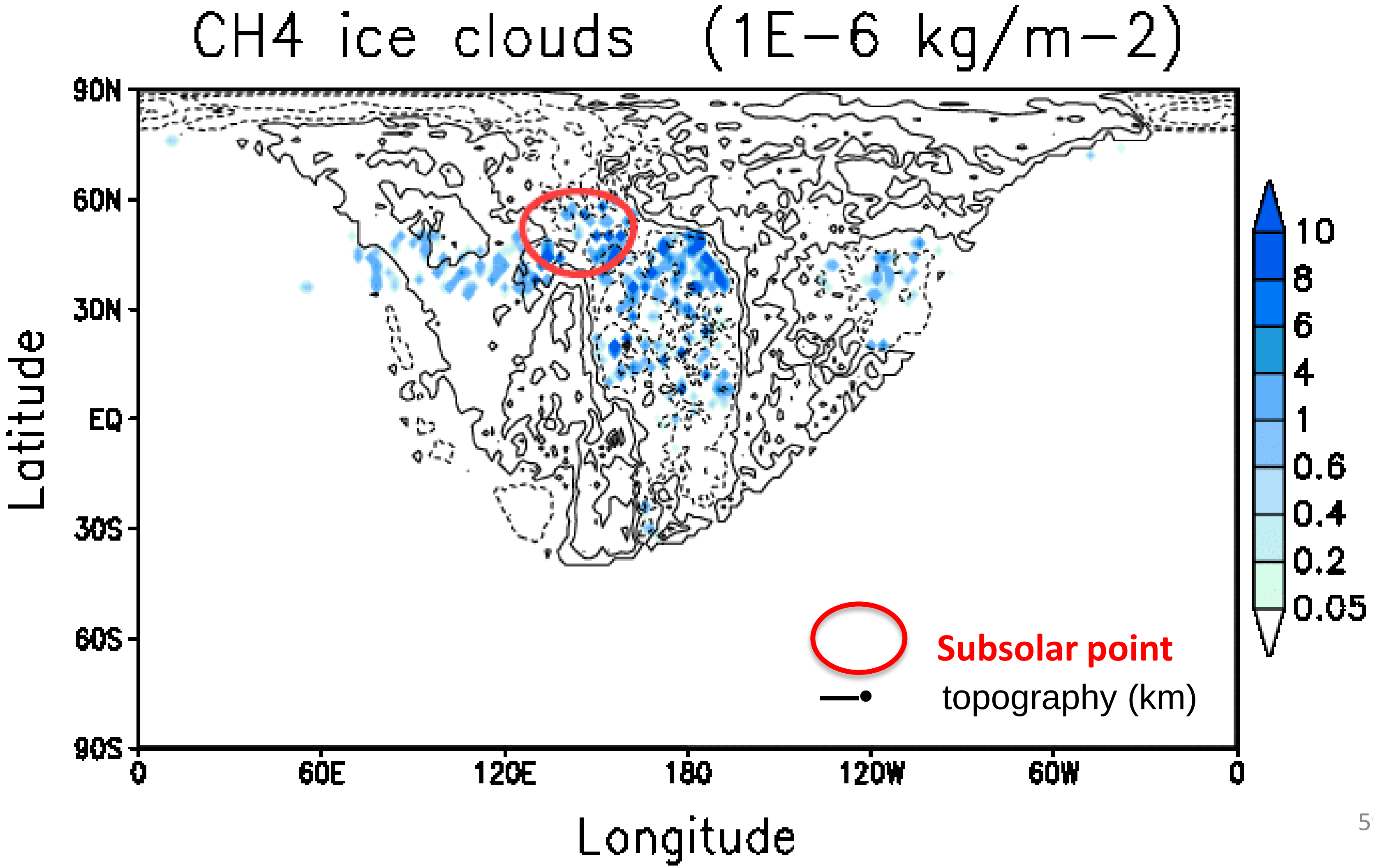
Latent heat release is significant

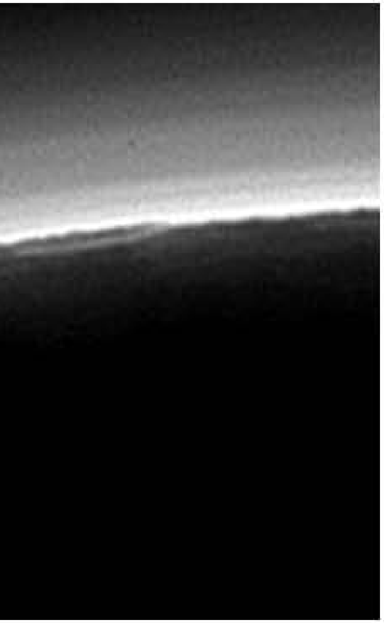
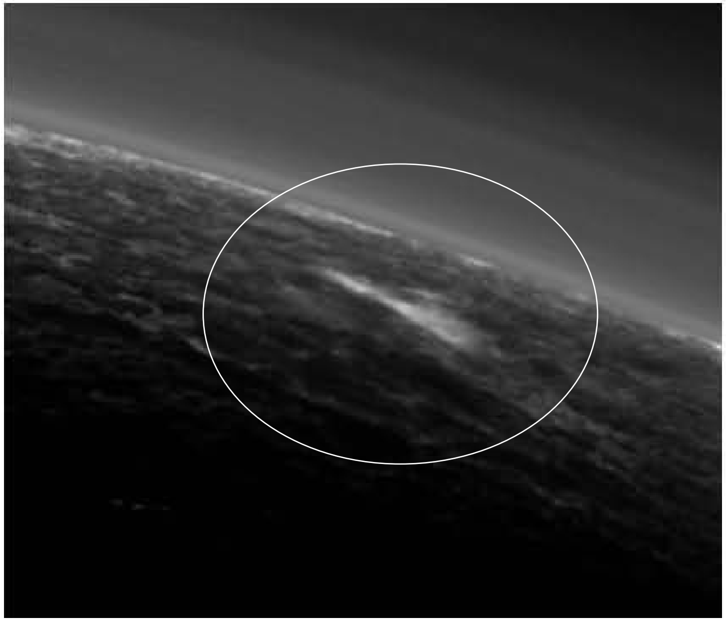
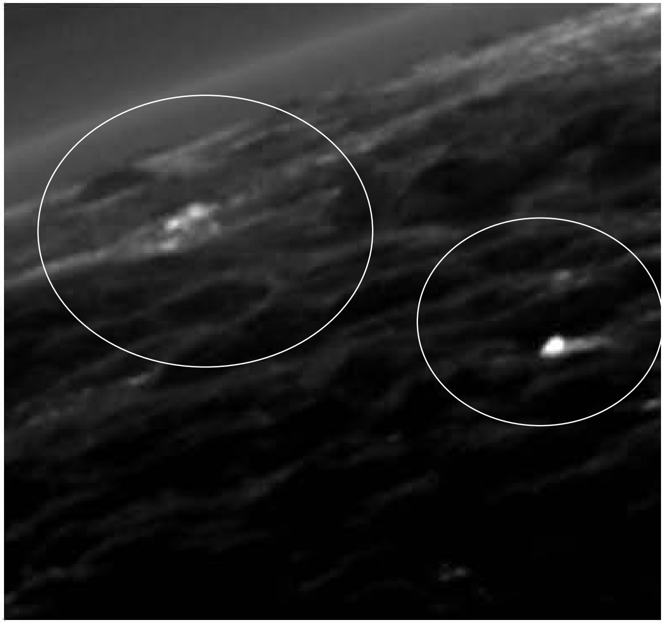
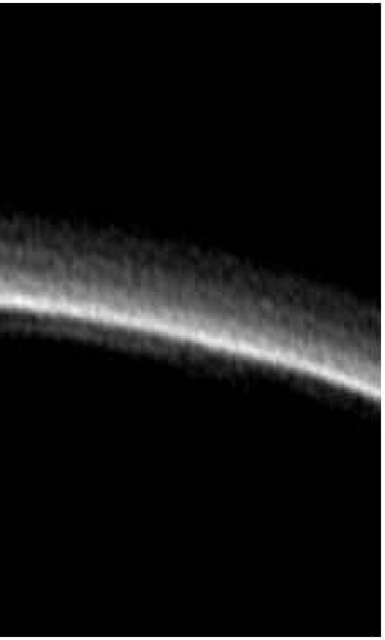
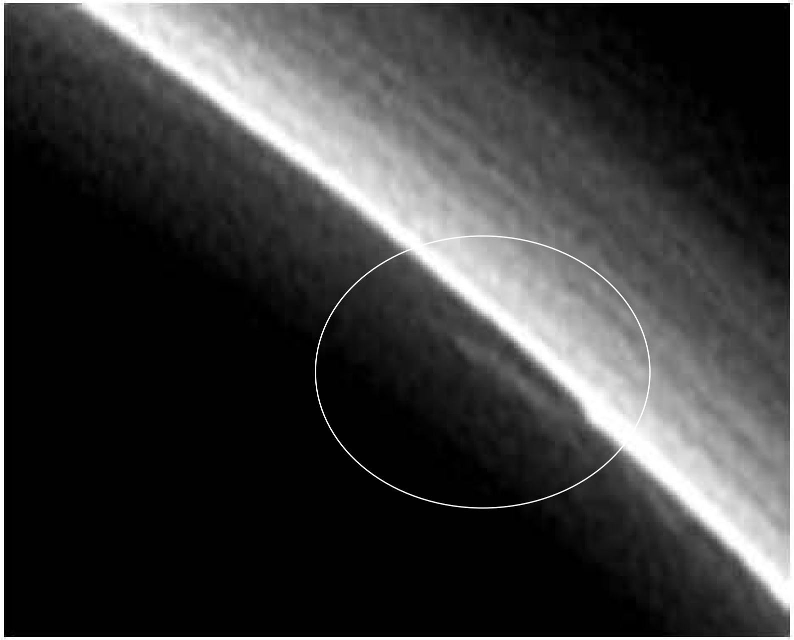
When N2 ice is present : CH4 Vapor pressure calculated assuming N2 : CH4 mixture with 0.3% CH4 (Merlin et al. 2015)

Formation of Methane ice clouds a few 100s of meters above surface where N2 ice sublimes

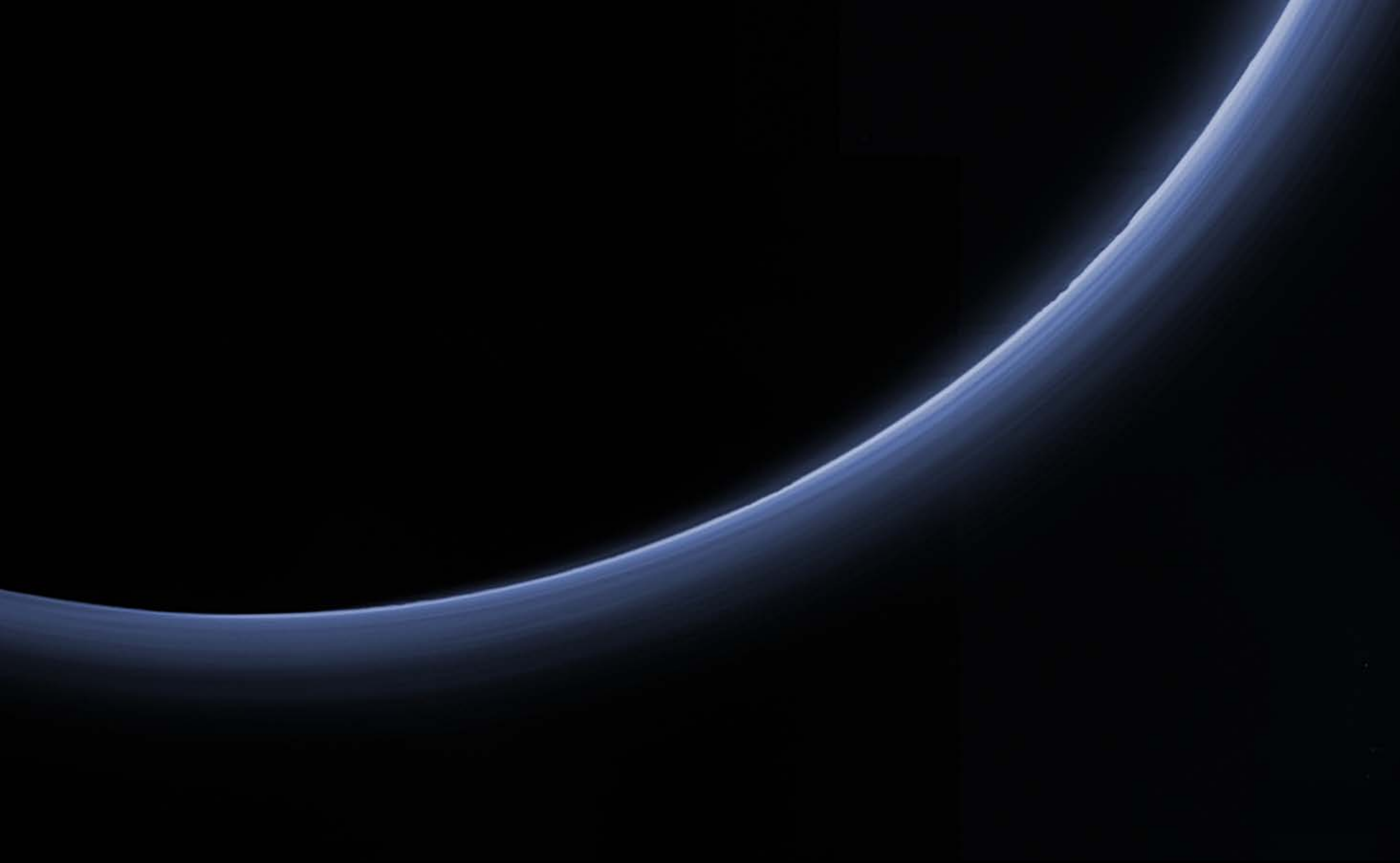
Case with N2 ice belt (180x90) Max visible opacity < 0.1





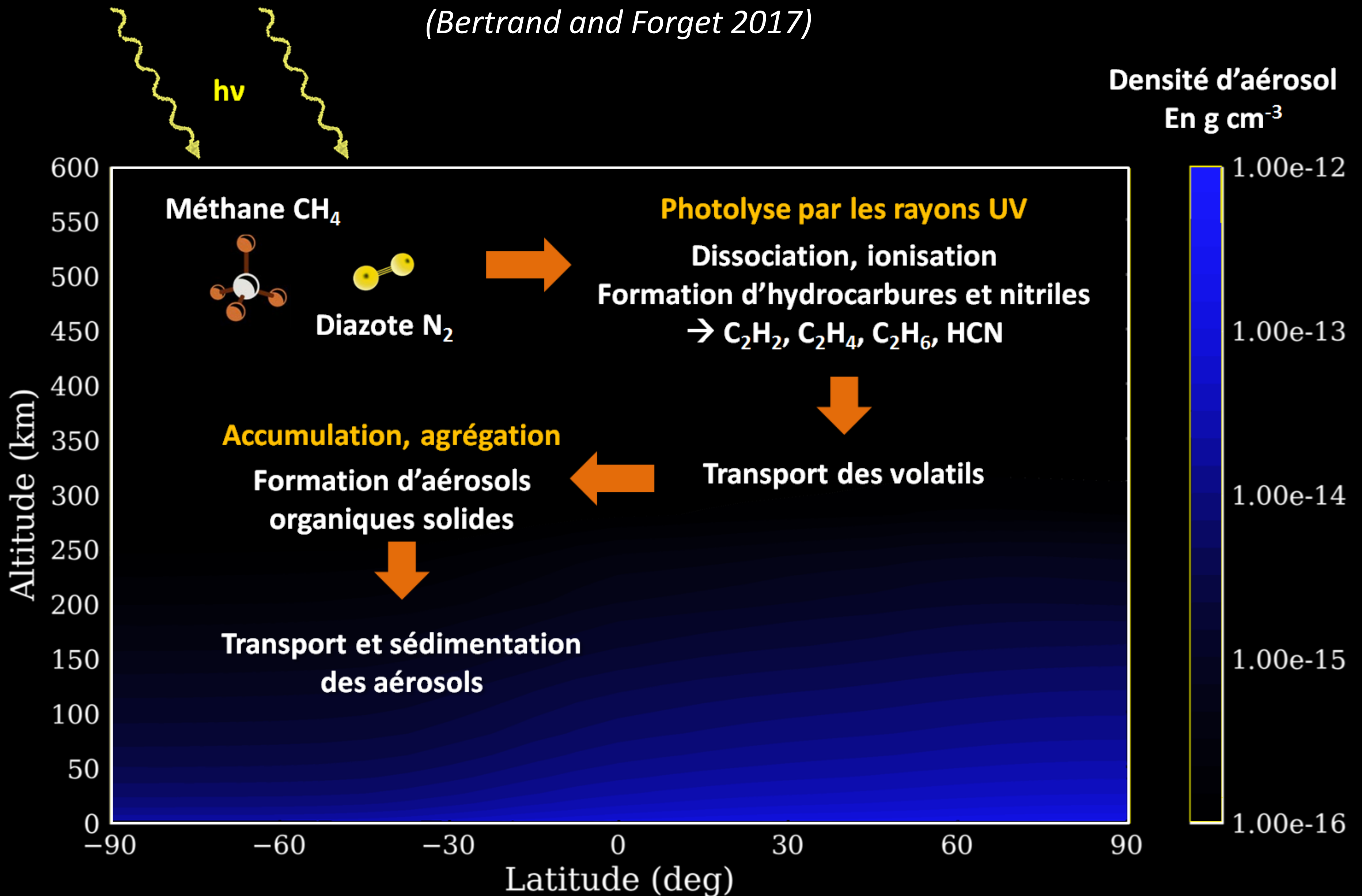
Cloud Condensation Pluton ?

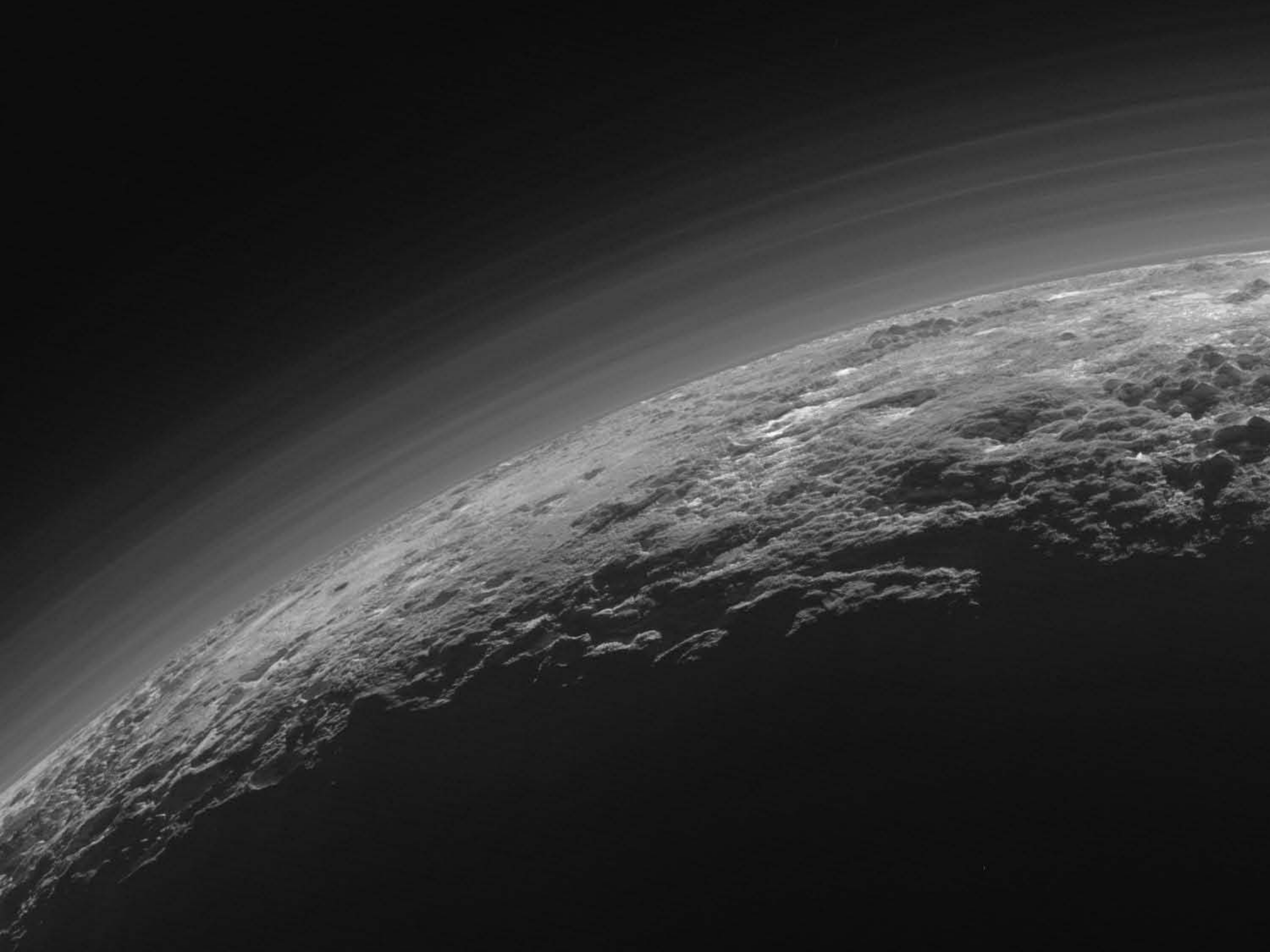


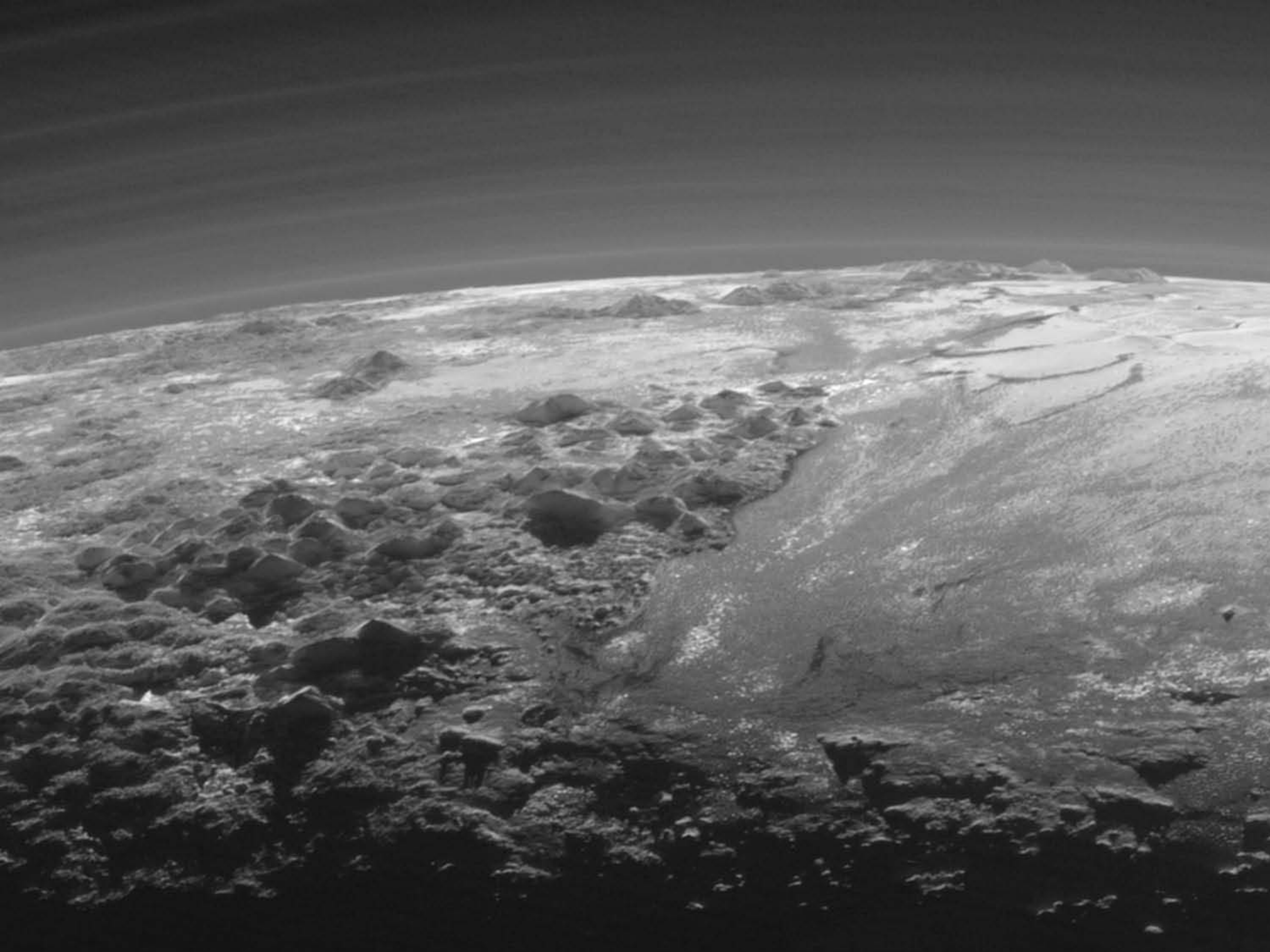
Organic Hazes

Modélisation des brumes organiques

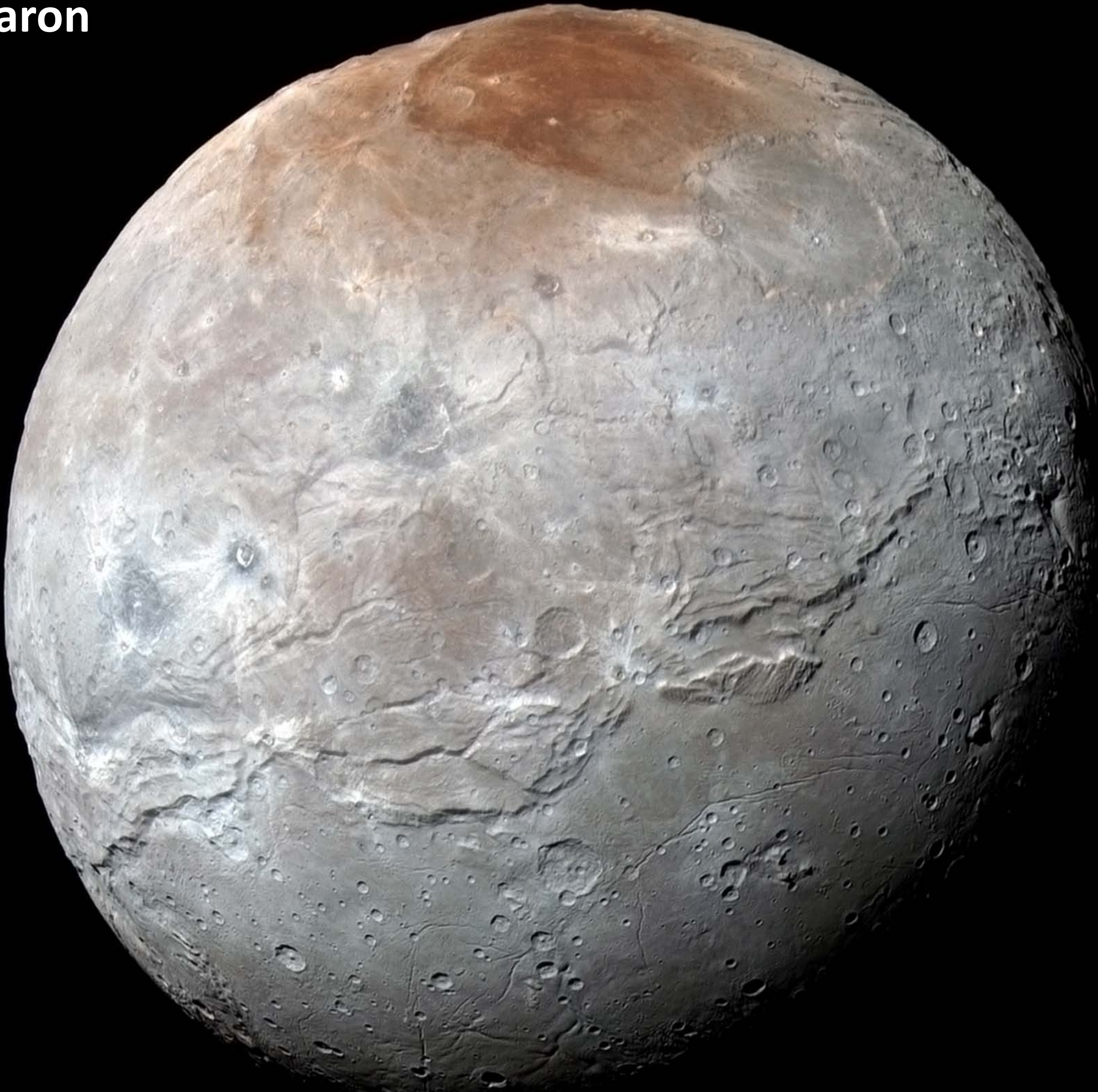
(Bertrand and Forget 2017)







Charon

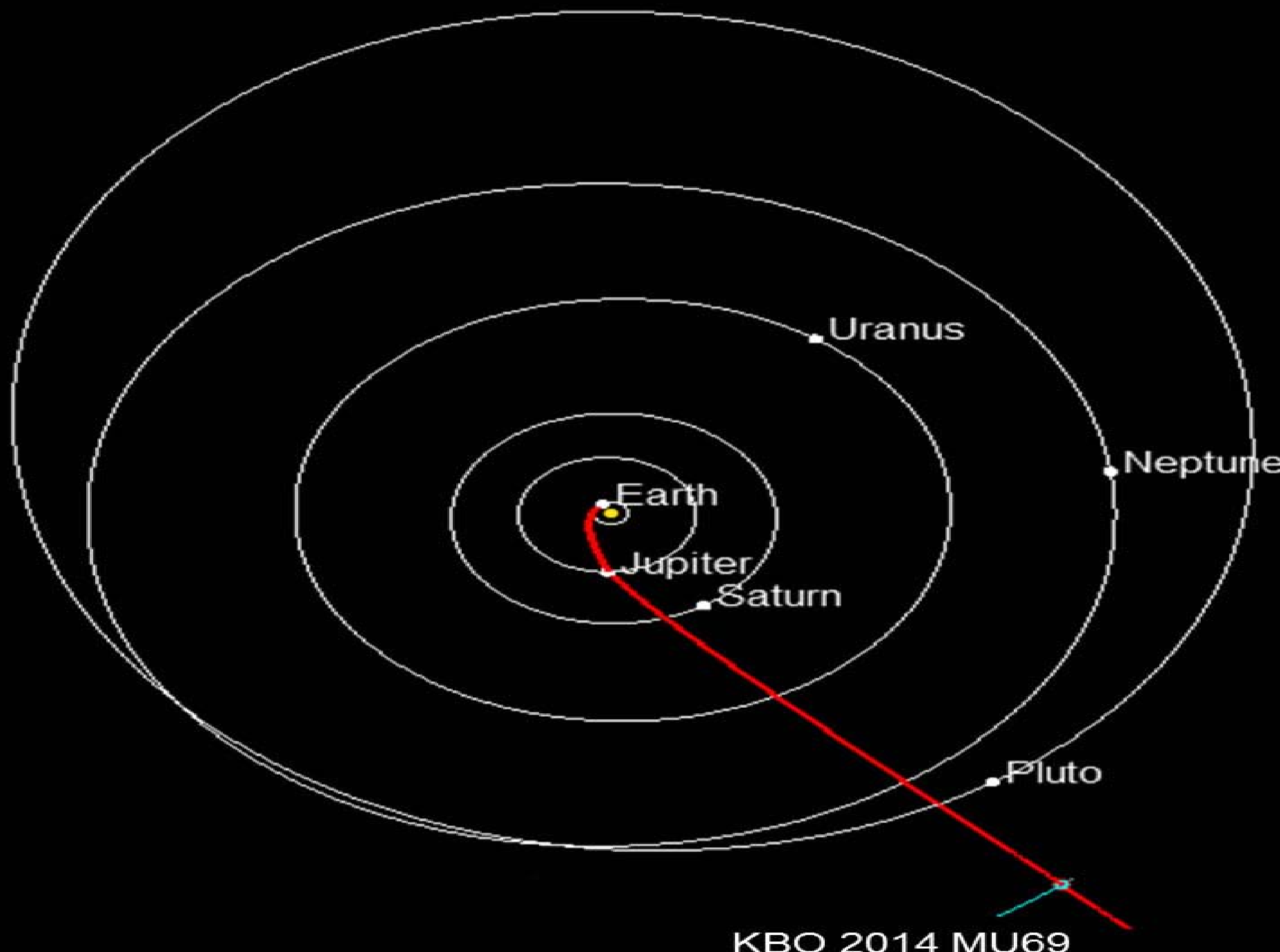


Charon and the 4 satellites seen by New Horizons

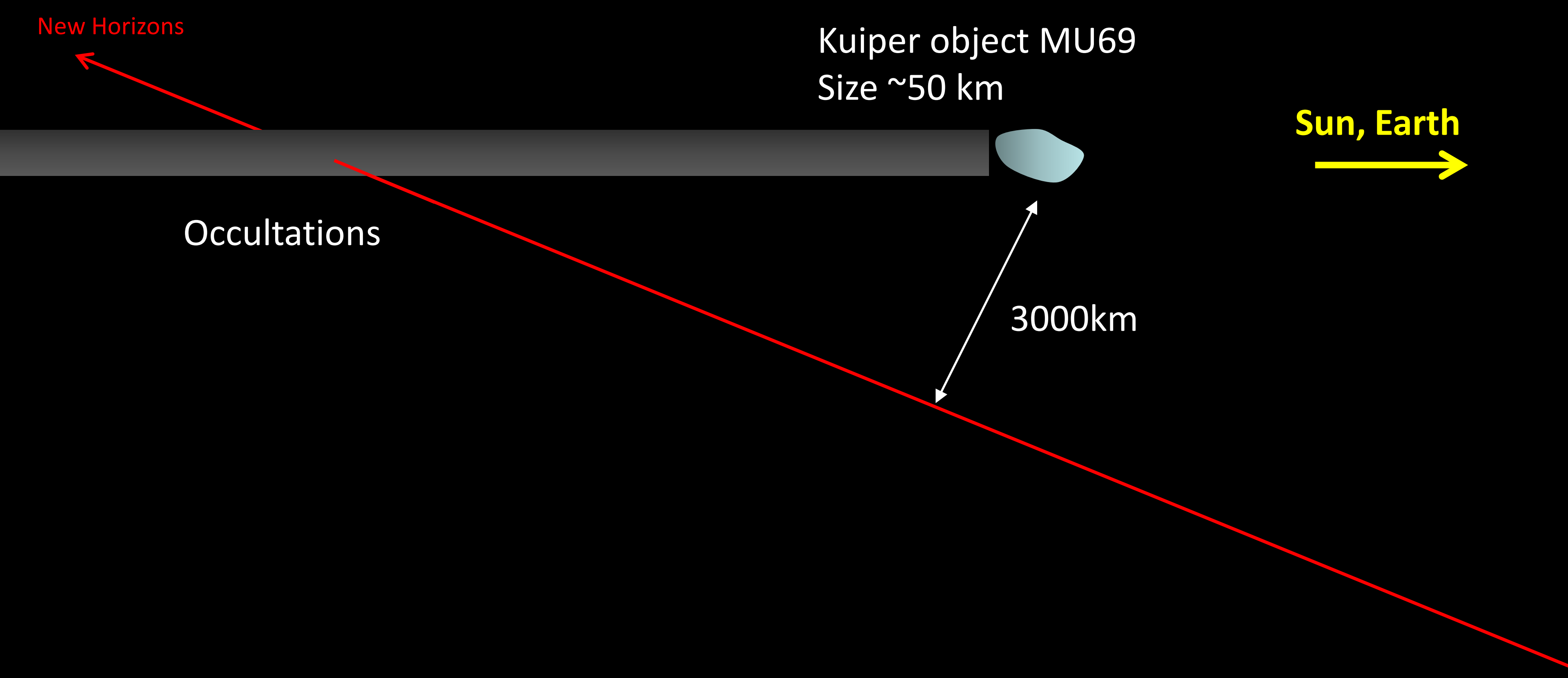
Albedo > 0.6   water ice ?

Next for New Horizons

Fly by of « MU69 » le 01/01/2019



Fly by of « MU69 » le 01/01/2019



Merci.