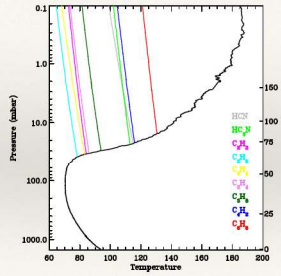
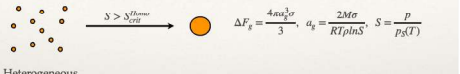
Condensates



Cloud Nucleation

Homogeneous

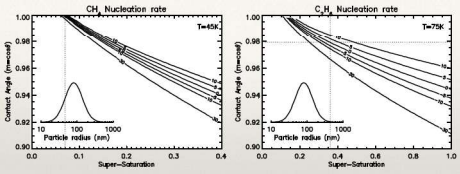


Heterogeneous

Ion

Typically $S_{crit}^{Homo} > S_{crit}^{Ion} > S_{crit}^{Hete}$

Contact angle from lab experiments



Curtis et al. 2008
$S_{cr}CH_4 = 1.07$
$S_{cr}C_2H_6 = 1.36$

$m_{CH4} = 0.995$
$m_{C2H6} = 0.979$

Condensation/Sublimation

Continuity equation for clouds

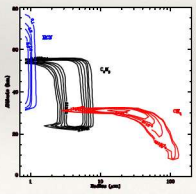
$$\frac{\partial n_p(v_p)}{\partial t} = -\frac{1}{r^2}\frac{\partial(r^2\Phi(v_p))}{\partial r} - \frac{\partial}{\partial m}\left(\frac{dm}{dt}n_p(v_p)\right) + \left.\frac{\partial n_p}{\partial t}\right|_{nucl}$$

Kelvin's law

$$y = exp\left(\frac{2\sigma M}{RT\rho r}\right)$$

Condensation or sublimation rate

$$\frac{dm}{dt}(r,S) = 4\pi r p_S(T) A_0 \frac{S-y}{1+A_0 A_1 p_S(T)}, A_0 = \frac{DMf_V}{RT}, A_1 = \frac{L}{kTf_V}\left(\frac{LM}{RT}-1\right)$$



HCN nucleates but only partially covers haze

C_2H_6 clouds grow up to 10 μm with the average size at 5 μm

CH_4 clouds grow up to 100 μm

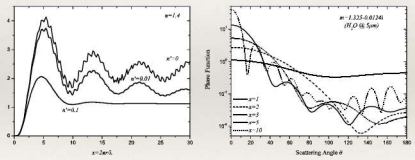
How do we use the particle size distributions?

Optical properties

Mie-Debye theory for homogeneous spheres

Analytic solution for interaction of EM field with a sphere of radius r and refractive index m

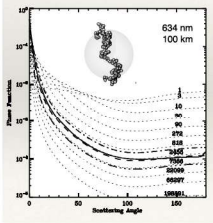
Qext, Qsct, P(θ), polarisation



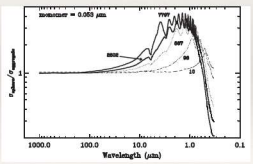
Optical properties

Mean Field theory for aggregates (Tomasko et al. 2008, Tazaki et al. 2018, Rannou et al. 2024)

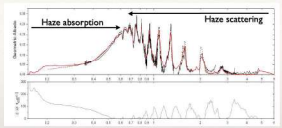
T-matrix for arbitrary shapes (Mishchenko et al. 1996)



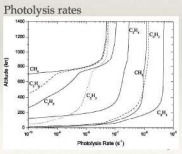
Aggregates with D_f=2



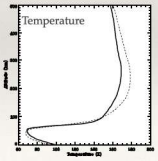
INTERACTION



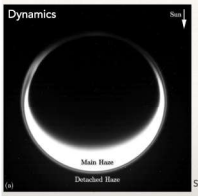
Photolysis rates



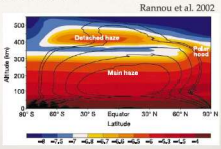
Temperature



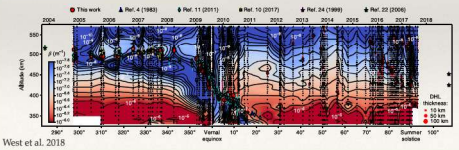
INTERACTION



Rannou et al. 2002

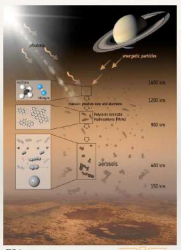


Seignovert et al. 2017



West et al. 2018

TITAN OVERVIEW



ESA

DRAGONFLY

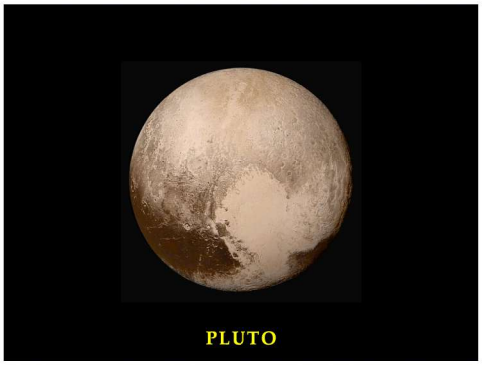
Haze formation through molecular growth initiated by the photolysis of CH_4 and N_2 (Waite et al. 2007, Coates et al. 2009, Wahlund et al. 2009 Lavvas et al. 2011, 2013)

Ion reactions drive a rapid molecular growth in Titan's upper atmosphere and generate the embryos of aerosols.

The embryos grow further through neutral chemical reactions on their surface which also affect the gaseous composition.

Aerosol production yield ~30% of total photolysis mass flux

Does the same picture apply to other environments ?

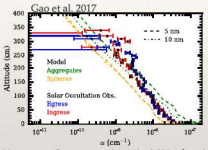


New Horizons Visible wavelengths 2015

RADIUS:	1190 km
COMPOSITION:	N_2, CH_4(5x10⁻³), CO(5x10⁻⁴)
GRAVITY:	0.65 m/s²
TEMPERATURE:	37 K
SURFACE PRESSURE:	~10 μbar
ORBIT:	32 AU

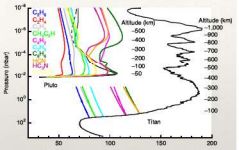
How much and what kind of haze is formed on Pluto?

Gao et al. 2017



Haze mass flux assumed 100% of CH_4 photolysis.

Could there be another process contributing to Pluto's haze formation?

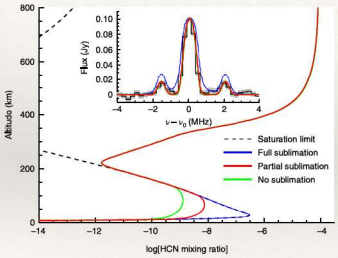


Most photochemical products can condense at high altitudes in Pluto's atmosphere

How important could this formation pathway be?

Particle composition has major implications for their optical properties, thus how the particles affect the atmospheric temperature.

First species to condense at high altitudes is HCN

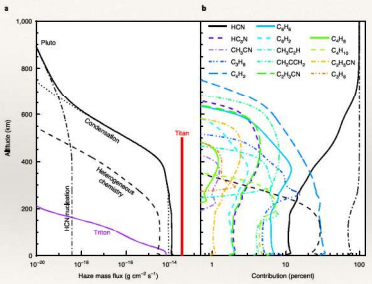


Slow condensation kinetics due to low temperature & density resulting to HCN supersaturation

Condensation gradually becomes efficient resulting to large loss of HCN.

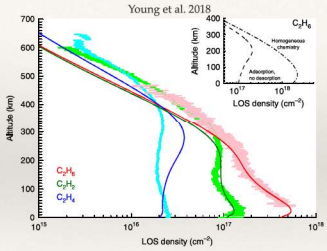
HCN from ALMA observations (Lellouch et al. 2017)

Contributions from photochemical products



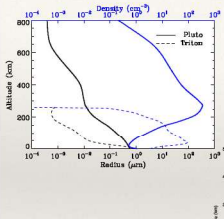
Heterogeneous Processes

Alice UV occultations
Young et al. 2018

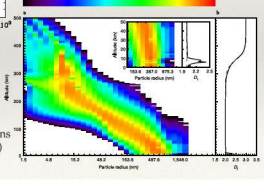


Heterogeneous reactions (adsorption & desorption) required to explain the C_2H_x profiles

Particle Shape



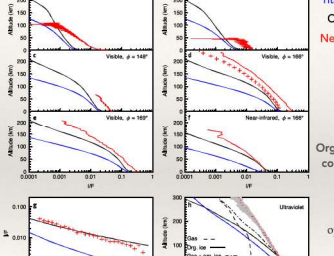
Transition from spherical growth (condensation) to aggregate growth (coagulation)



Primary particle size of ~10 nm, consistent with New Horizons observations (Gladstone et al. 2016, Cheng et al. 2017)

Haze Observations

Lavvas et al. 2021



Titan-type haze with 30% yield

Organic Ice Condensates

New Horizons Observations

Cheng et al. 2017
Grundy et al. 2018
Young et al. 2018

Organic Ice could be a major component of Pluto's haze

Photochemical gases could contribute to the opacity attributed to haze

JWST observations indicate the contribution of organic ices (Lellouch et al. 2023).