Atmospheres on Volatile-Bearing Kuiper-Belt Objects

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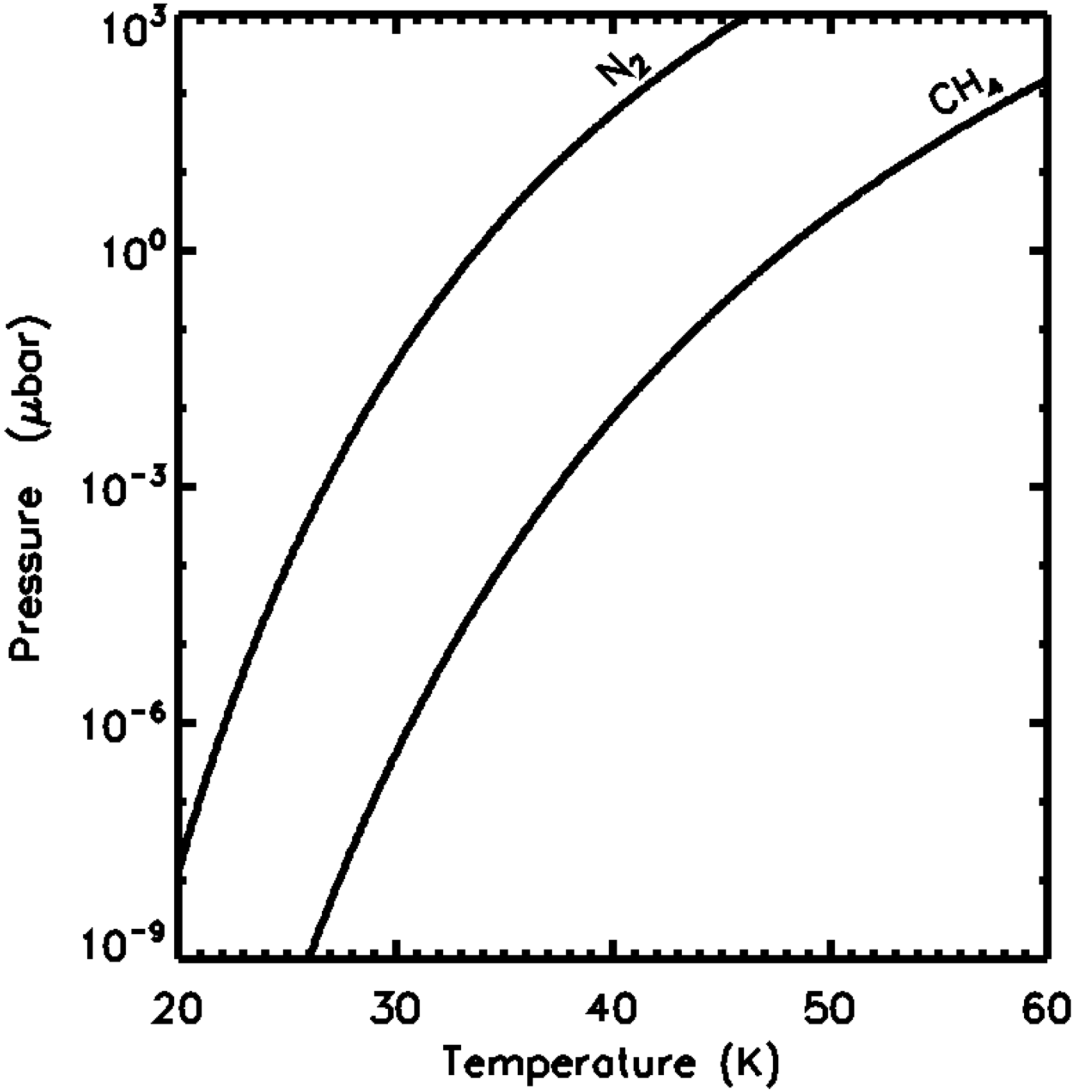
Volatiles detected in the Kuiper Belt

	Body	Volatiles	Diameter	Bond Albedo	Atmosphere
Large, bright, N_2-rich	Triton	N_2, CH4, CO	2707 km	0.80	14 μbar
	Pluto	N_2, CH_4, CO	2356 km	0.67	~17 μbar
	Eris	N_2, CH_4	2326 km	0.55	<1 nbar
Smaller, mostly dark, CH_4-rich	Makemake	CH_4	1466 km	0.62	<12 nbar
	2007 OR_{10}	CH_4	1280 km	0.06	?
	Quaoar	CH_4	1070 km	0.09	<20 nbar
	Sedna	CH_4	995 km	0.19	?

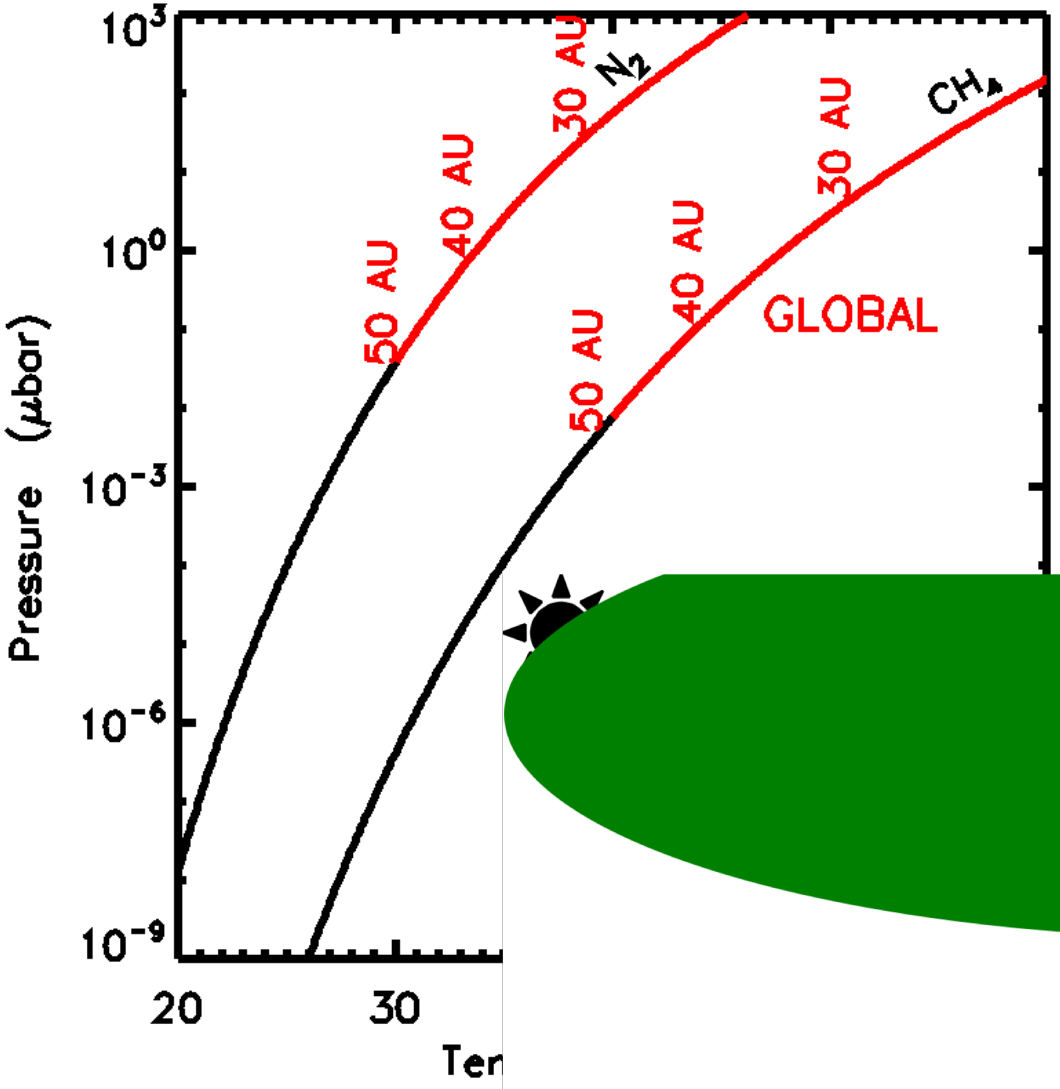
Volatiles: Triton: *Grundy et al. 2011*; Pluto: *Grundy 2013*; Eris: T*egler et al. 2012*; Makemake: *Tegler et al. 2008* (also some N_2 on from small CH_4 band shifts); 2007 OR_{10}: *Brown 2011* (inferred from color); Quaoar: *Dalle Ore et al. 2009*; Sedna: *Barucci et al. 2010*. **Diameter & Bond albedo of volatile:** Triton: *Thomas 2000, Stansberry et al. 1990*; Pluto: *Lellouch et al. 2009 & 2011*; Eris: *Sicardy et al. 2011*; Makemake: *Ortiz et al. 2012*, *Stansberry et al. 2008*; 2007 OR10: *Santos-Sanz 2012*; Quaoar: *Fornasier et al. 2013*; Sedna: *Pal et al. 2012*. **Atmosphere:** Triton: *Gurrola 1995*; Pluto: *Lellouch et al. 2009*; Eris: *Sicardy et al. 2011*; Makemake: *Ortiz et al. 2012*; Quaoar: *Braga-Riba et al. 2013*.

Vapor-pressure & atmospheric regimes

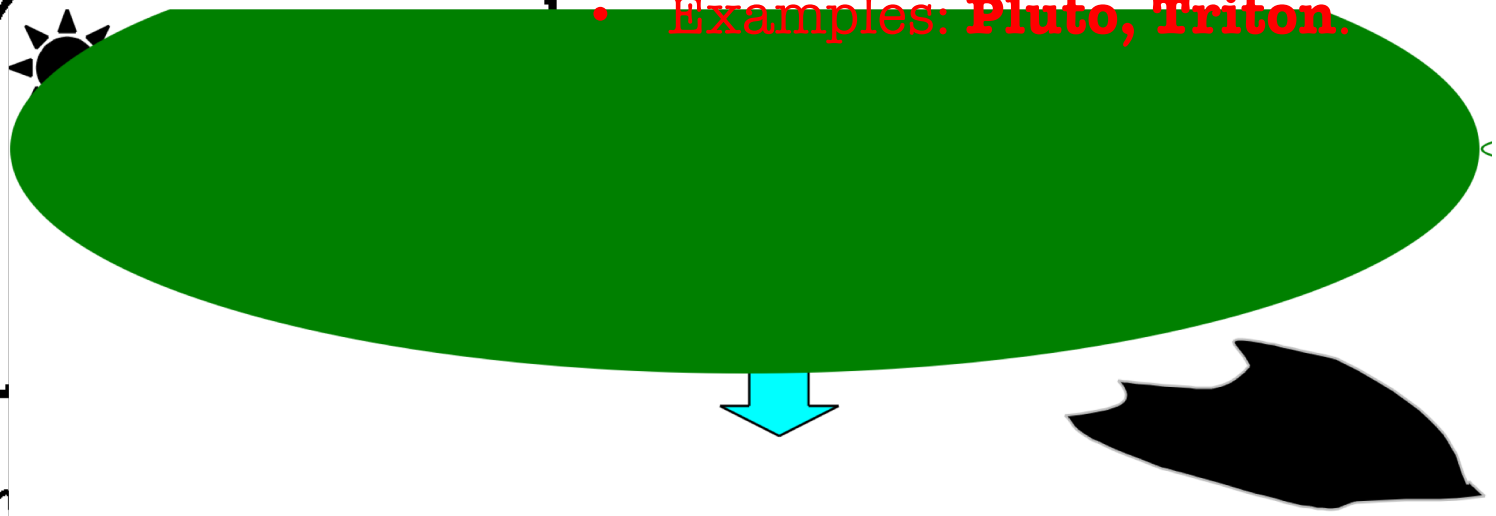


- **Equilibrium vapor pressure** is a very sensitive function of volatile ice temperature.

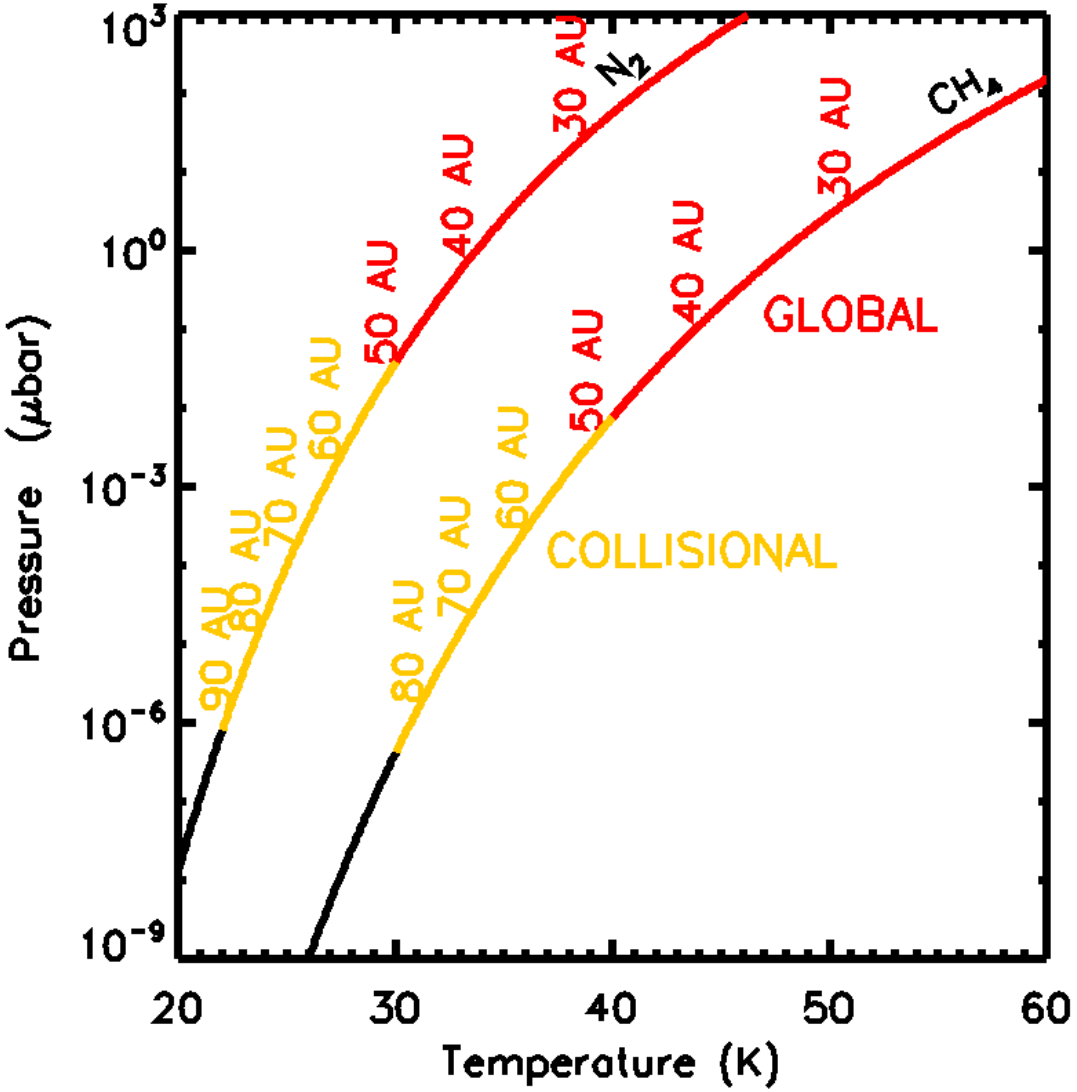
Vapor-pressure & atmospheric regimes



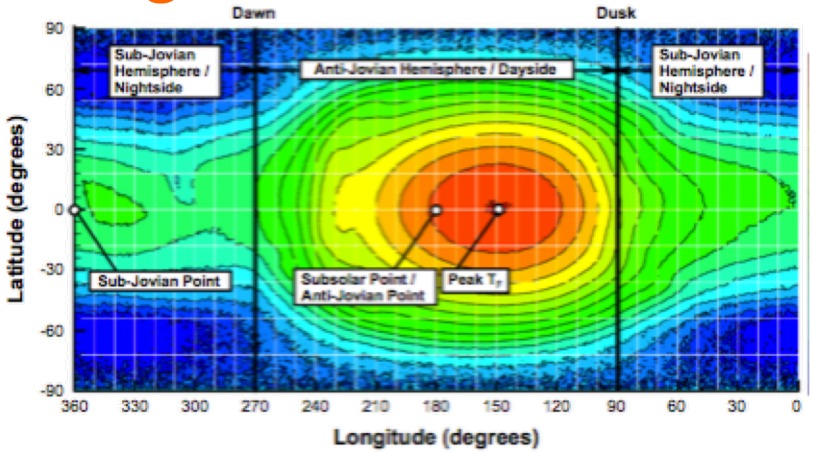
- At pressures above ~1-100 nbar, the atmosphere is **global**, with nearly constant pressures.
- Winds, waves, hazes, photo-chemistry, Pluto-like escape. Atm. detectable by stellar occultation.
- Examples: **Pluto, Triton**.



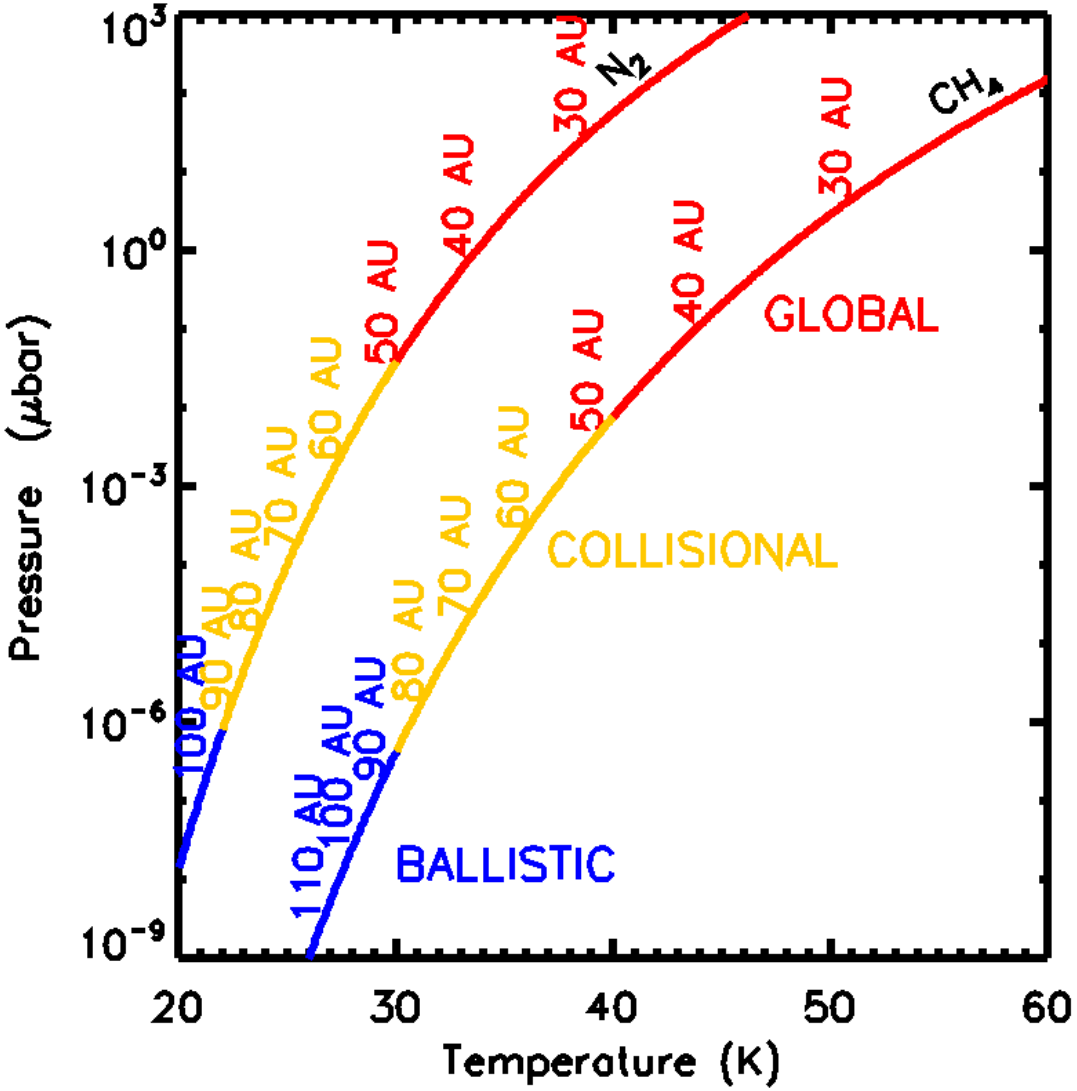
Vapor-pressure & atmospheric regimes



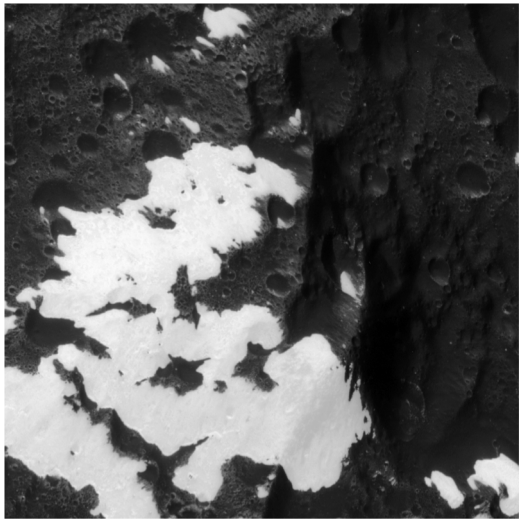
- For pressures above ~1 picobar, the atmosphere is **collisional**.
- Column density greater than ~10^{17} cm^{-2}; opaque to UV. Atmospheric chemistry, sublimation flow, Pluto-like escape. Detectable by UV occultation.
- Example: **Io subsolar region**.



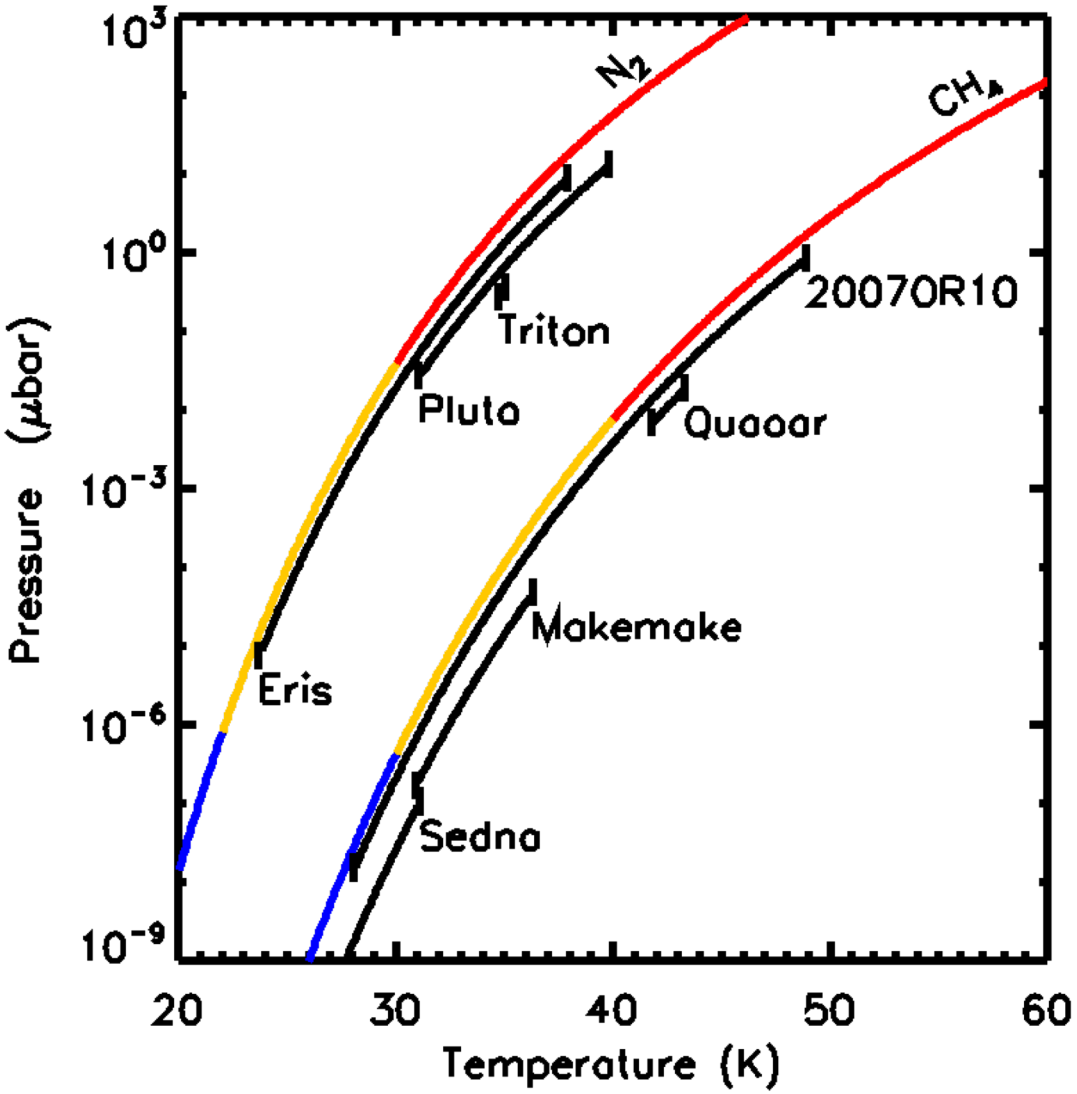
Vapor-pressure & atmospheric regimes



- For pressures less than ~ 1 picobar, the atmosphere is **ballistic** (surface-bounded exosphere).
- Loss is by Jean's escape.
- Volatiles can still move slowly from warm areas to cold traps.
- Example: **Iapetus**.

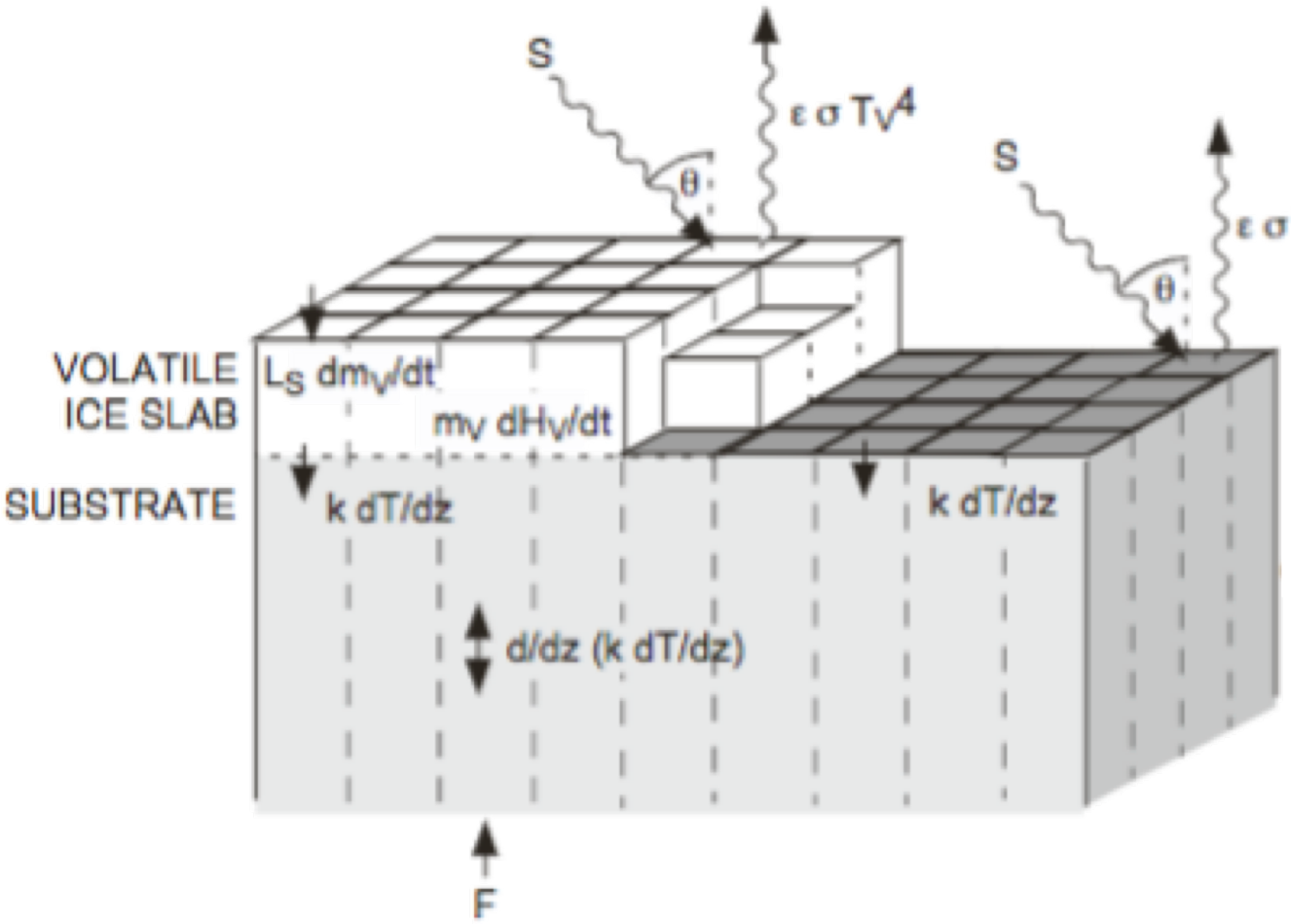


Vapor-pressure & atmospheric regimes



- Simple thermal equilibrium suggests most volatile-bearing KBOs have **collisional** or **global** atmospheres at some part of their orbit. *Stern and Trafton 2008.*
- This might explain the high albedos of Pluto, Triton, Eris, and Makemake. *Stern et al. 1988*; *Licandro et al.*
- Simple thermal equilibrium is not enough (e.g., Triton is too cold).

Modeling seasons with VT3D (Young 2012, 2013; Olkin submitted)



- Track each latitude.
- Global mass balance; volatile migration
- Local energy balance: sunlight, thermal emission, conduction, internal heat flux.
- *Very fast*. Run a suite of thermal inertia values and volatile inventory.

Thermal inertia and internal heat

	Body	Thermal parameter for pure water ice	Internal flux / solar
Large, bright, N_2-rich	Triton	34	8%
	Pluto	29	5%
	Eris	29	16%
Smaller, mostly dark, CH_4-rich	Makemake	29	3%
	2007 OR_{10}	18	1%
	Quaoar	15	1%
	Sedna	49	49%

Thermal parameter 2200 tiu (fluffy to pure water ice).

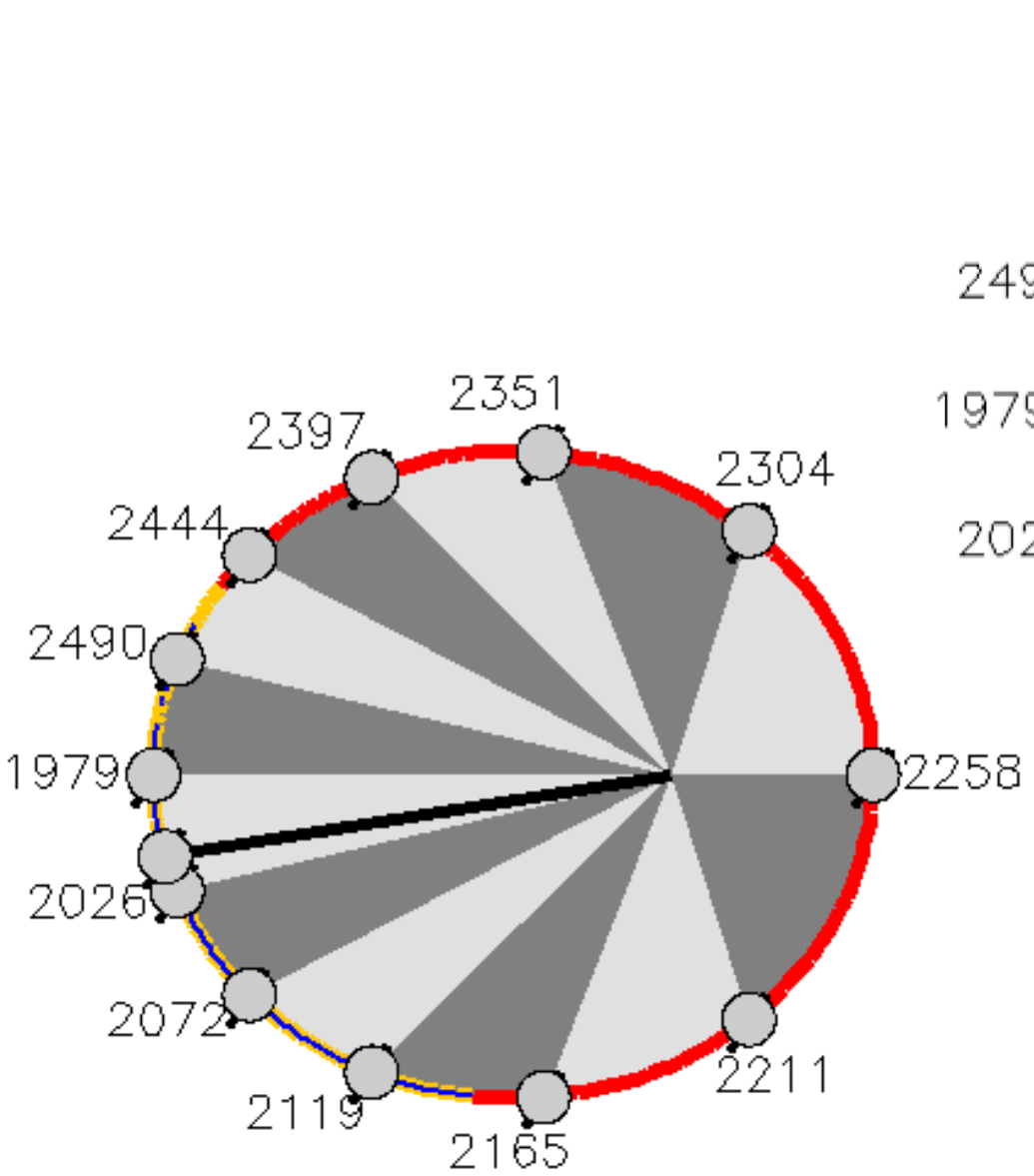
(thermal inertia) * (2π/period)$^{1/2}$/(emisivity * σ * (avg. temperature)^3)

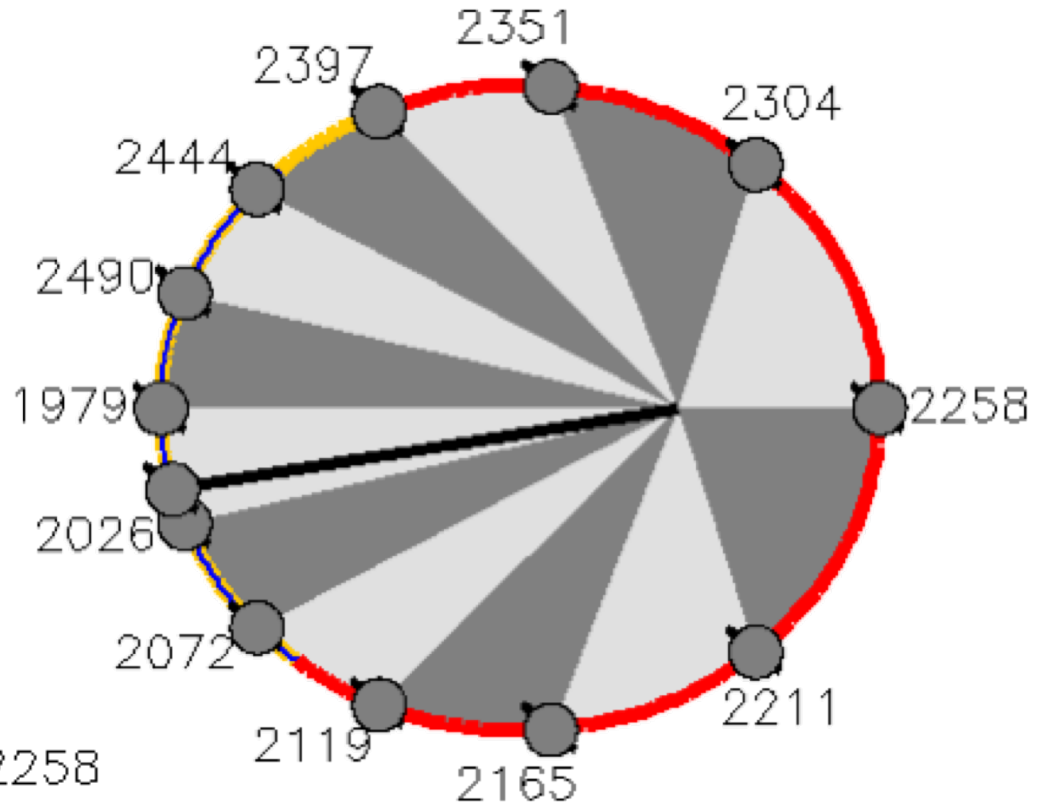
Large parameter means thermal inertia is important.

Young 2012, 2013; Spencer et al. 1989.

Internal flux and absorbed solar flux: Estimated current heat flux compared with solar flux absorbed by a volatile-covered body.

Example results: Eris, two poles. A=0.5, Γ=32 tiu, 10^3 g/cm^2 N_2





Summary of results

	Body	Global?	Ballistic at all latitudes?
Large, bright, N_2-rich	Triton	Always	Never
	Pluto	Always	Never
	Eris	~50% of orbit	Never
Smaller, mostly dark, CH_4-rich	Makemake	Never	Never
	2007 OR_{10}	up to 30% of orbit	up to 60% of orbit
	Quaoar	Always (8% if <= 10 g/cm^2 CH4)	Never
	Sedna	Never	98-100% of orbit

Notes: Triton: *Spencer & Moore 1992*; Pluto: *Young 2013; Olkin submitted*; Eris, Makemake, 2007 OR10, Quaoar, Sedna: *This work*.

Summary of sublimation atmospheres