Orion? ~~Spacecraft-~~Asteroid water interactions during the Asteroid Redirect Mission (ARM)

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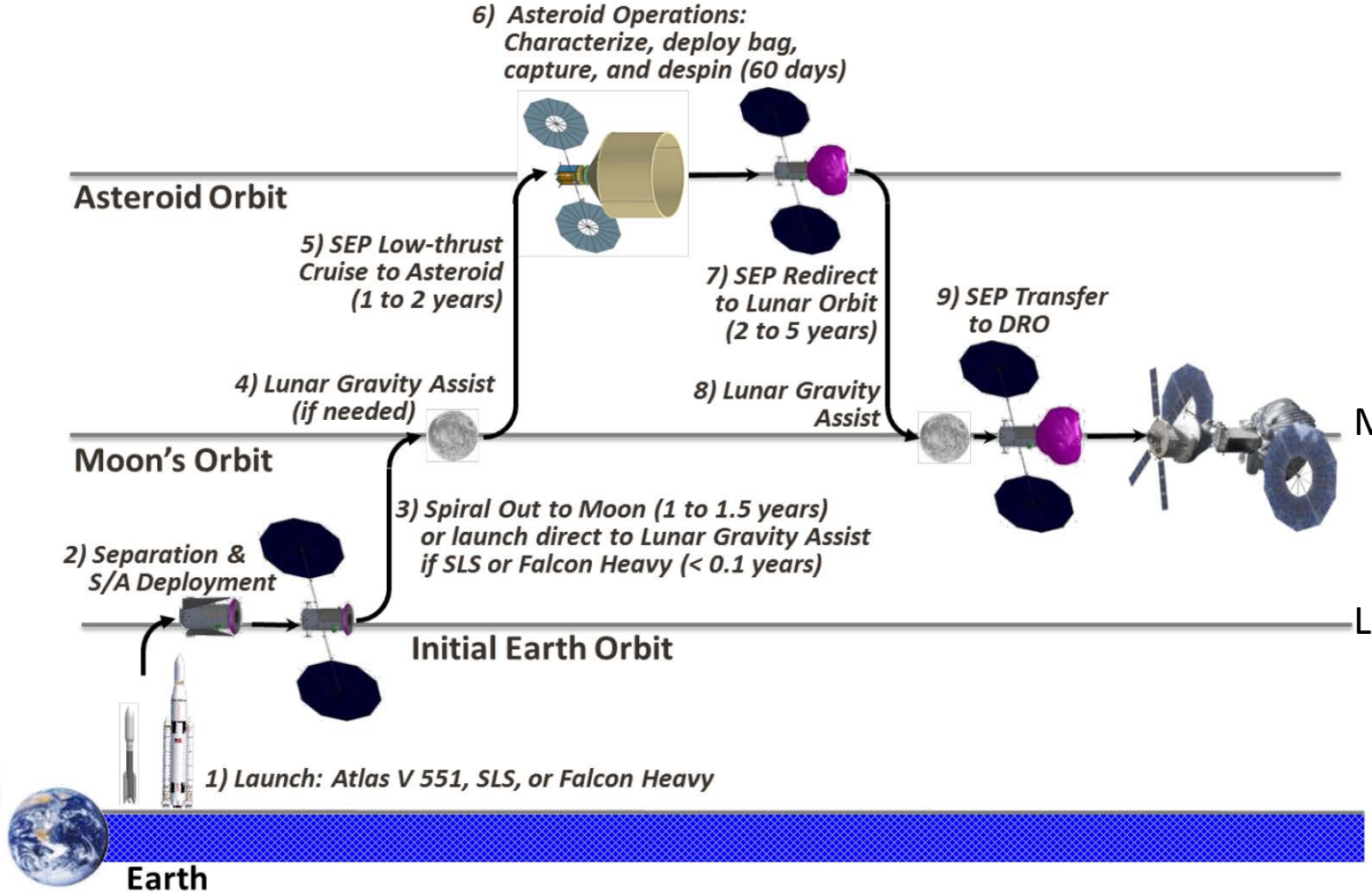
Asteroid Redirect Mission

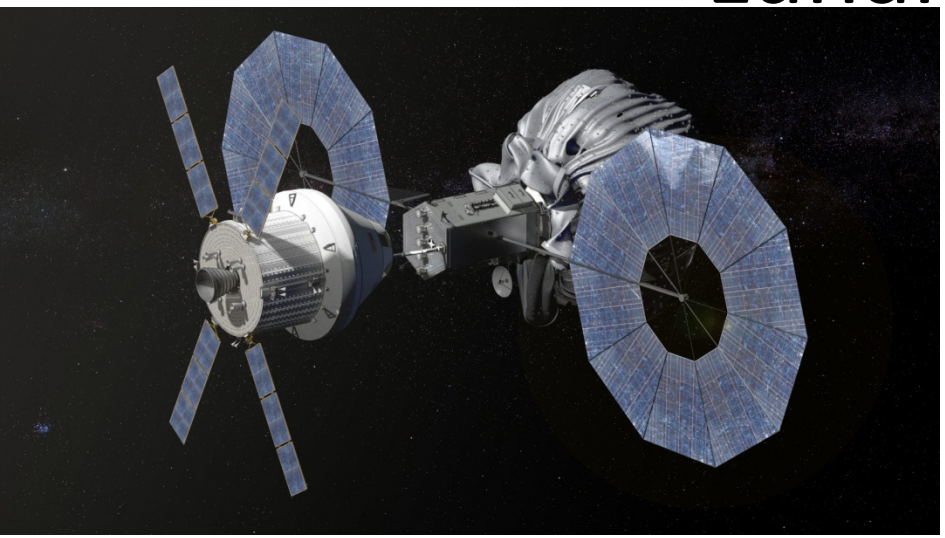


Mid 2020s ?

Late 2010s ?

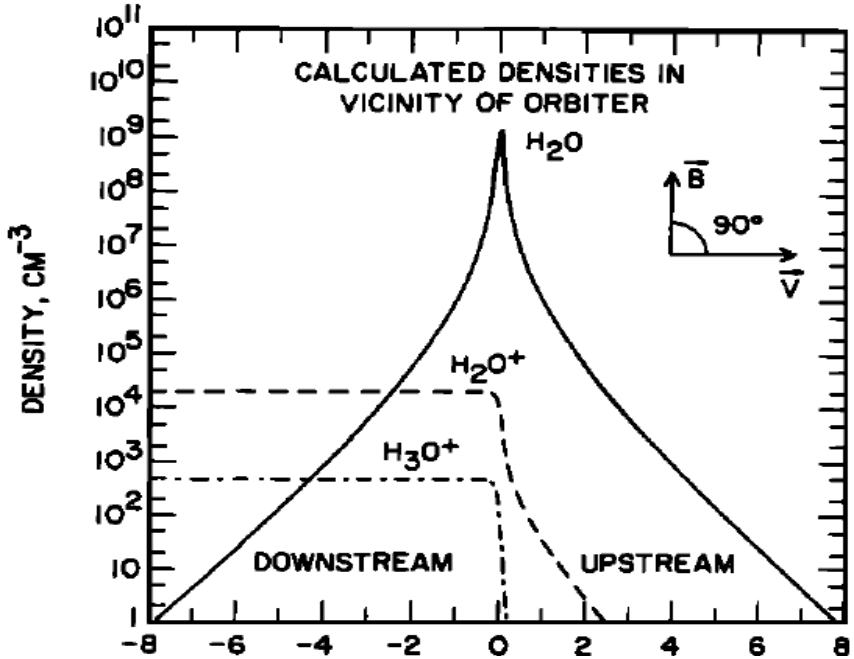
Get a whole vs pick up a rock

Orion to Rendezvous with NEA in Lunar orbit

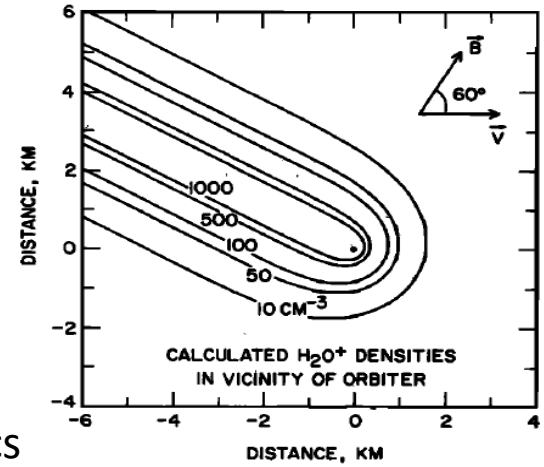


- Asteroid Environment: Fragile!
- Environmental impact from human system interaction:
  - Spacecraft outgassing & NEA surface contamination

Orion Water Outgassing

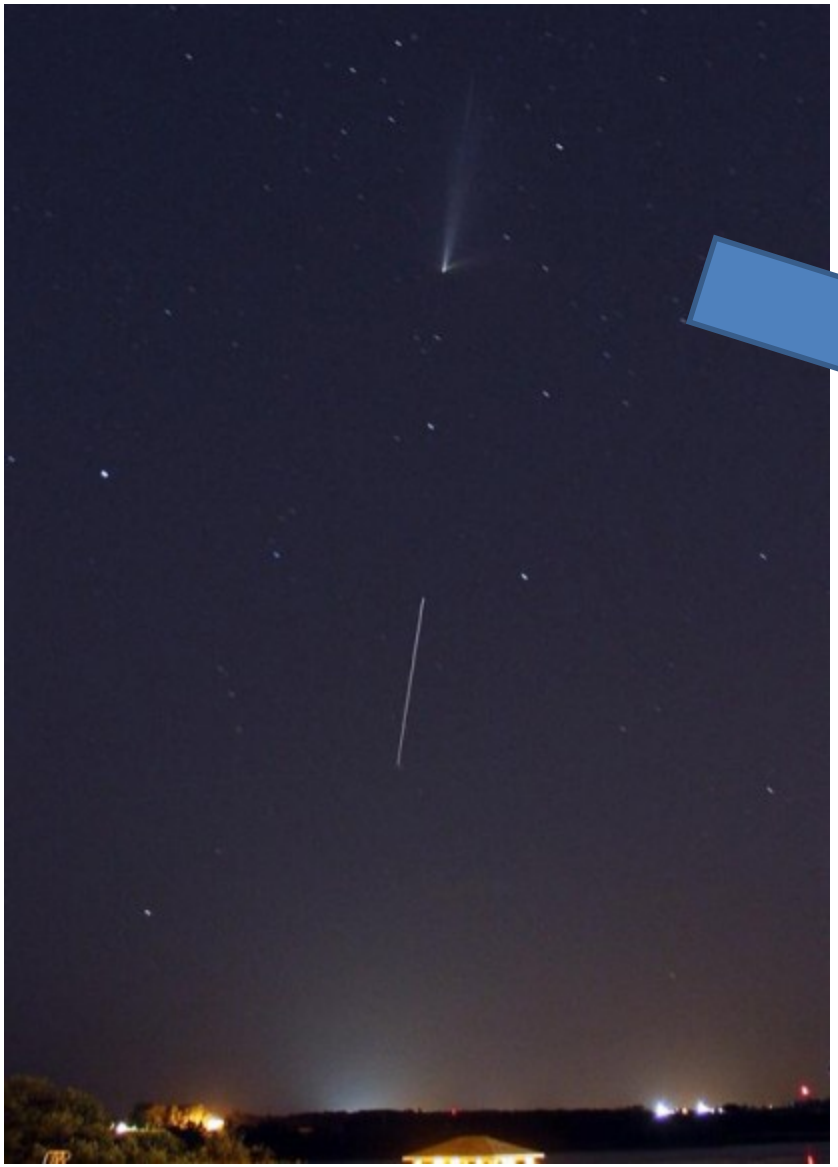


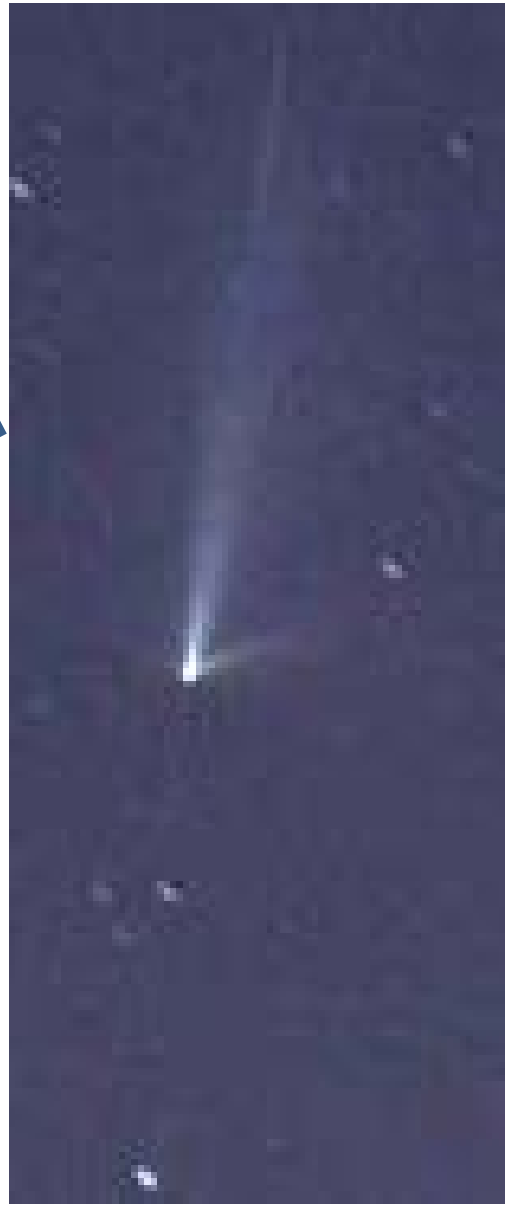
Plasma Diagnostics Package



Paterson and Frank, 1989

- Shuttle as an analog
- Info garnered during the 1985 SpaceLab-2 Mission using Plasma Diagnostics Package [Paterson and Frank, 1989]
- Orion should be the dominant atmosphere: Lots of Water!
- **Nominal outgassing:** ~$10^9/cm^3$ in vicinity and $10^6/cm^3$at 1 km [Paterson and Frank, 1989]
- **Large dumps:** STS-128 dumps ~70 kg, $10^{17}/cm^3$ in vicinity & $10^{11}/cm^3$ at 1 km





Cold, Dark Surface: A Water Cold Trap

- **Rate of water accumulation:** σ is the surface density [#/m^2]

$$d\sigma/dt = S - L$$

S= <nv> ; water flux to the surface from Orion

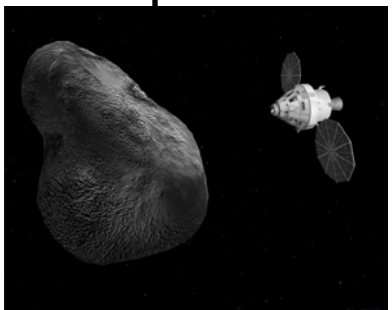
$L = \sigma/\tau_{td} + +\sigma/\tau_{pdissoc} + \sigma/\tau_{psd} + \sigma/\tau_{esd} - \nabla \bullet \Phi_{mig}$

(+ Sputtering losses + Impact vaporization losses)

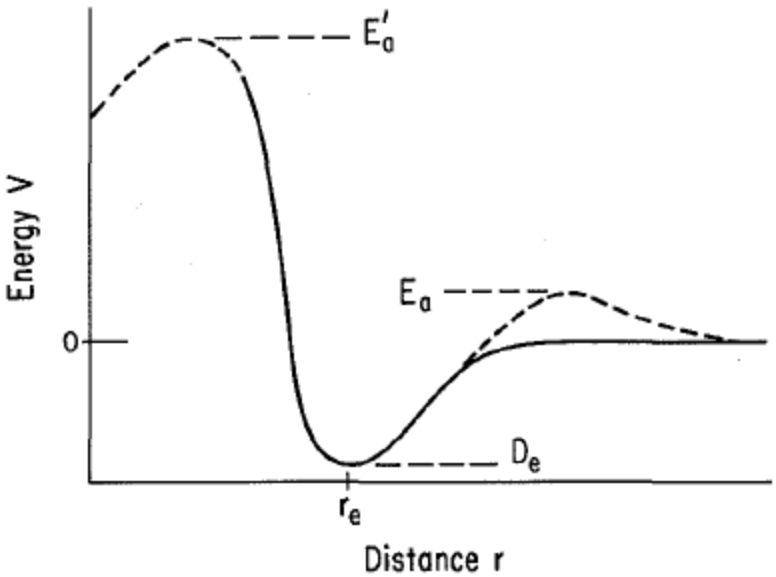
- For cold (~0K), dark surface, low gravity, water accumulates on the surface facing Orion, L~ 0:

$\sigma \sim \langle nv \rangle T$ with T being the exposure time

- ROMs: n = 10^{12}/m^3, v ~ 500 m/s [Paterson and Frank, 1989]
- Surface water accumulation: σ ~ 2 x 10^{18}/m^2 –hr of spacecraft exposure in dark
- After ~ 10 hours, get a monolayer of water



For a Finite Temperature: Fast Surface Loss via Thermal Desorption



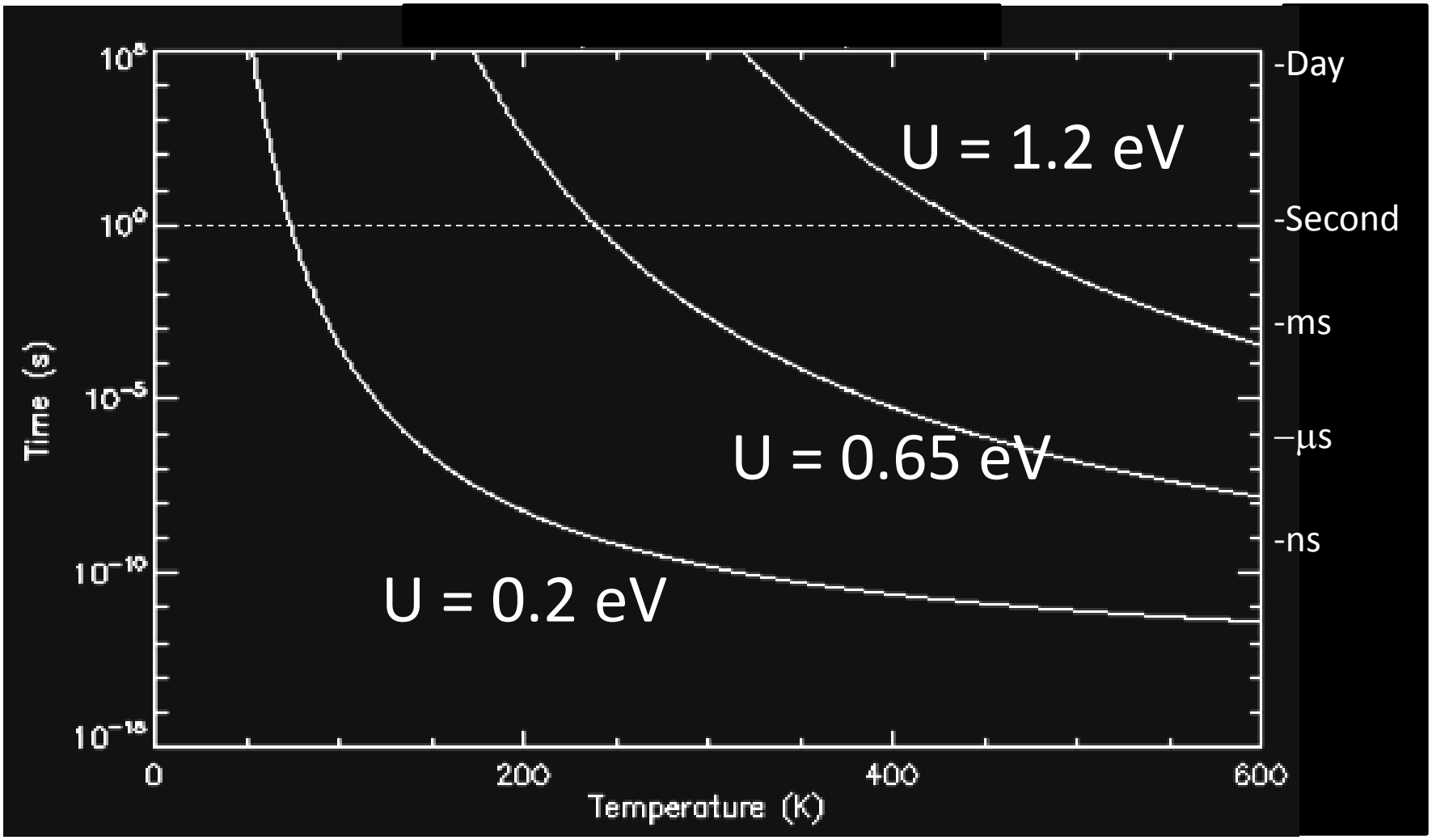
Hunten et al., 1987

- **Thermal desorption:** Warm surface releases water
- Temperature-Programmed Desorption (TPD) of water [Hibbitts et al. 2011; Poston et al., 2013, NLSI work]
- Polanyi-Wigner Eq.

$$\tau_{res} \sim \tau_{td} \sim 10^{-13} s\, e^{U/T}$$

  - U = Activation Energy (eV)
  - T= Temperature (eV)
- Large U typically associated with crystal irregularities /defects

Residency Time vs Temperature



-Strong function of both temperature and surface crystal defects that determine U
-Nice discussion of defects and water retention in Dyar et al. [2010]

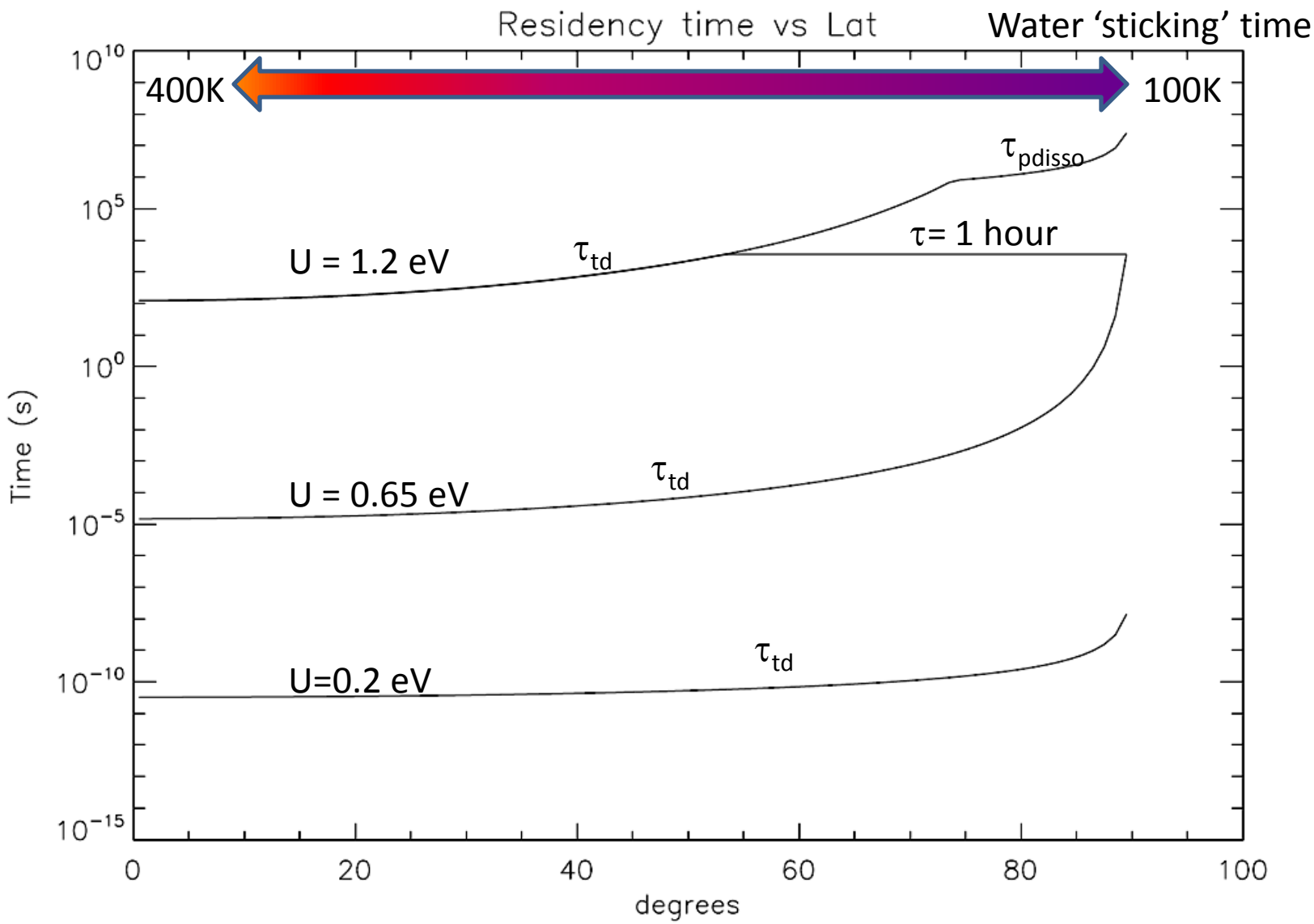
Adsorbed Water Flux: A Case Study

- **In Equilibrium:**

$$d\sigma/dt = 0 = nv\,\mathrm{Cos}(\theta) - \sigma/\tau_{td} - \sigma/\tau_{pdissoc}$$

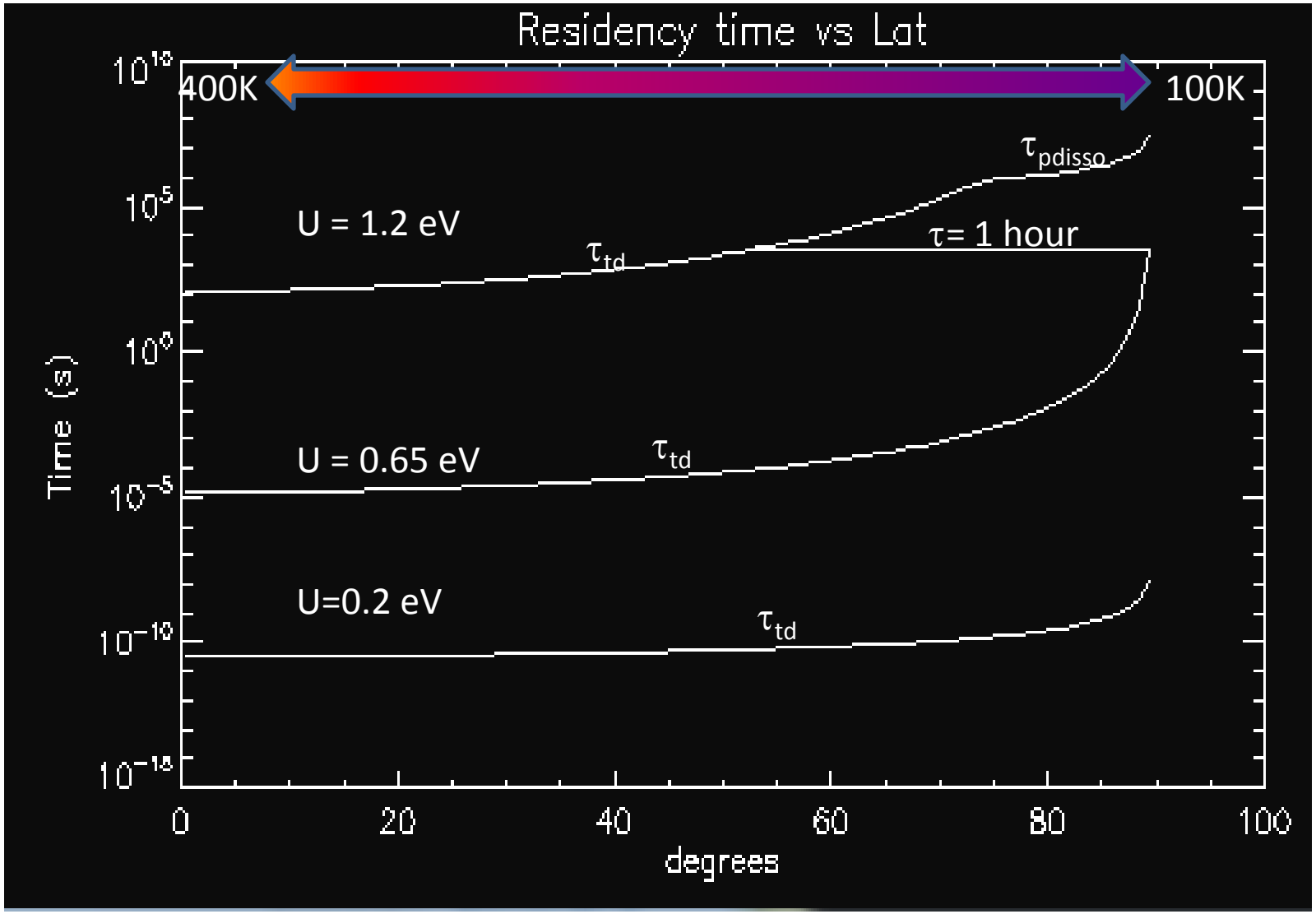
- **Asteroid in lunar orbit (contrived geometry)**
  - Assume a Moon-like asteroid surface temperature variation with SZA (400K at equator to ~100K terminator)
  - Orion at asteroid's equator located 1 km away
  - Assume a Shuttle-like source of water at 1 km of ~10^6/cm^3 at ~500 m/s
- If direct exposure in very cold regions longer than a couple days, then photo-dissociation losses become important:

$$\tau_{pdissoc} < \tau_{td}$$

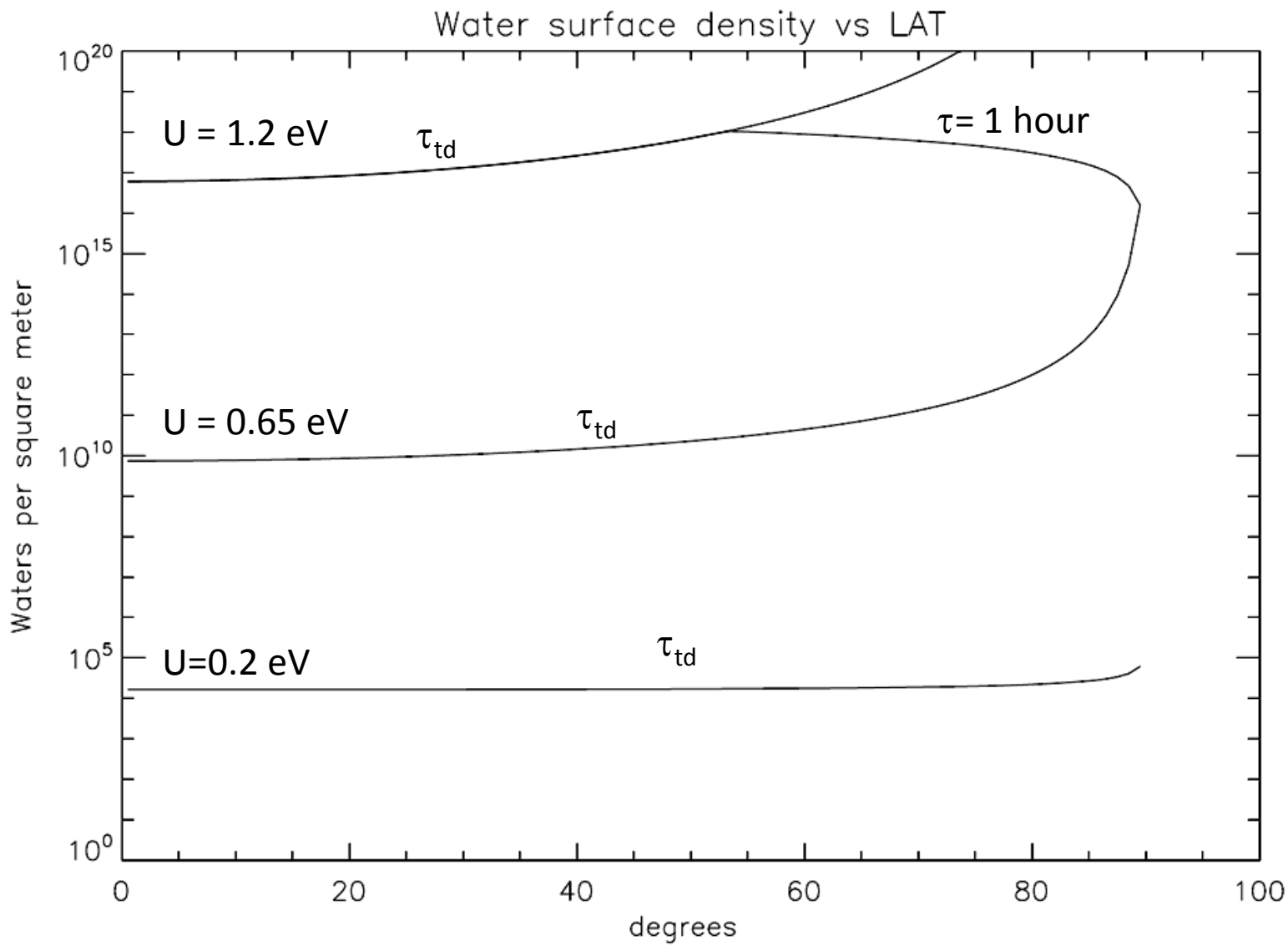


Key Takeaway: Temperature is important, but U (defects) are the defining variable

Water 'sticking' time



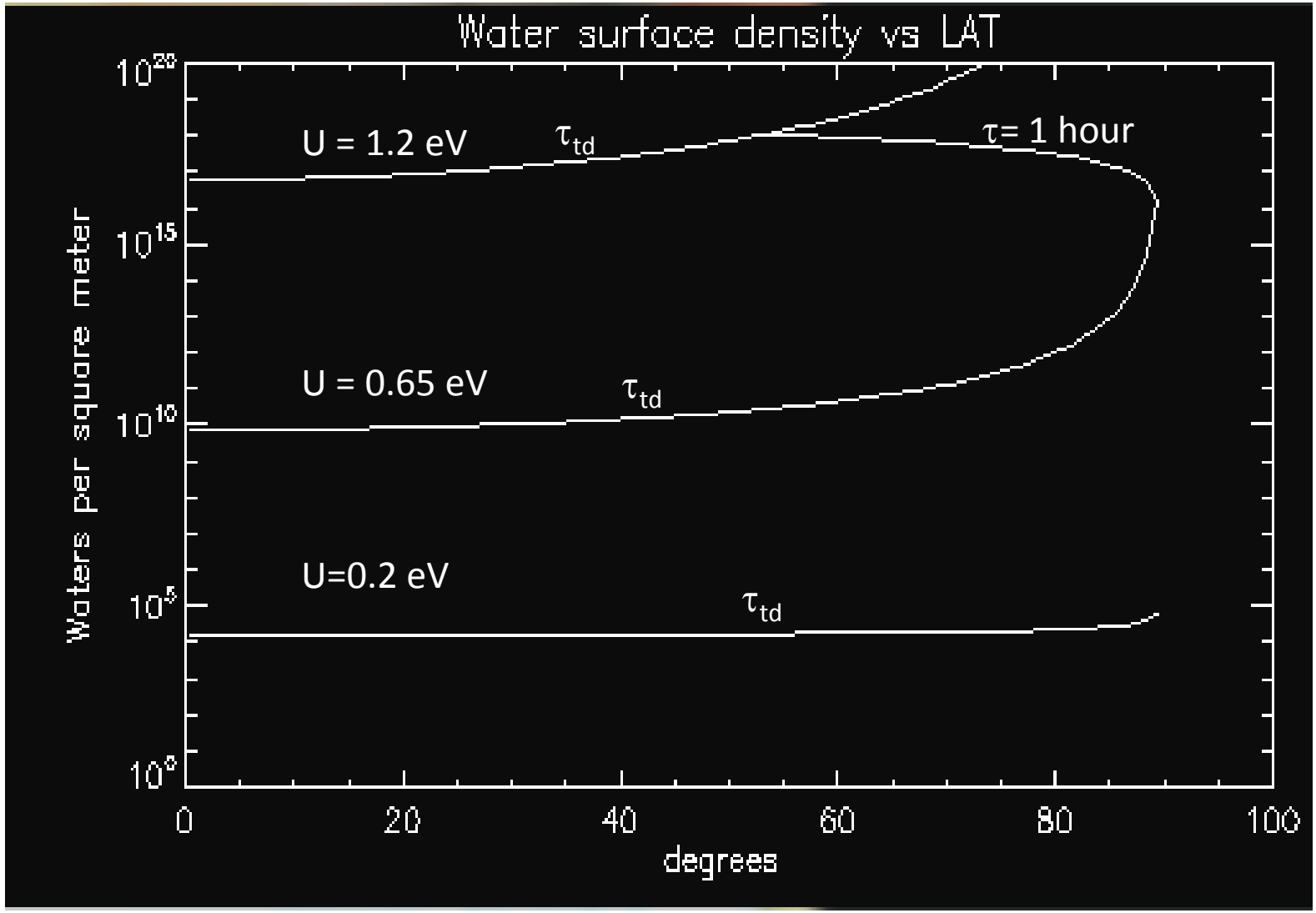
Key Takeaway: Temperature is important, but U(defects) are the defining variable



General trend: 1) Curves move vertically in direct proportion to n_w

2) Curves flatten with less extreme temperature range

Key Takeaway: Temperature is important, but defects (U) are the defining variable (U/T)

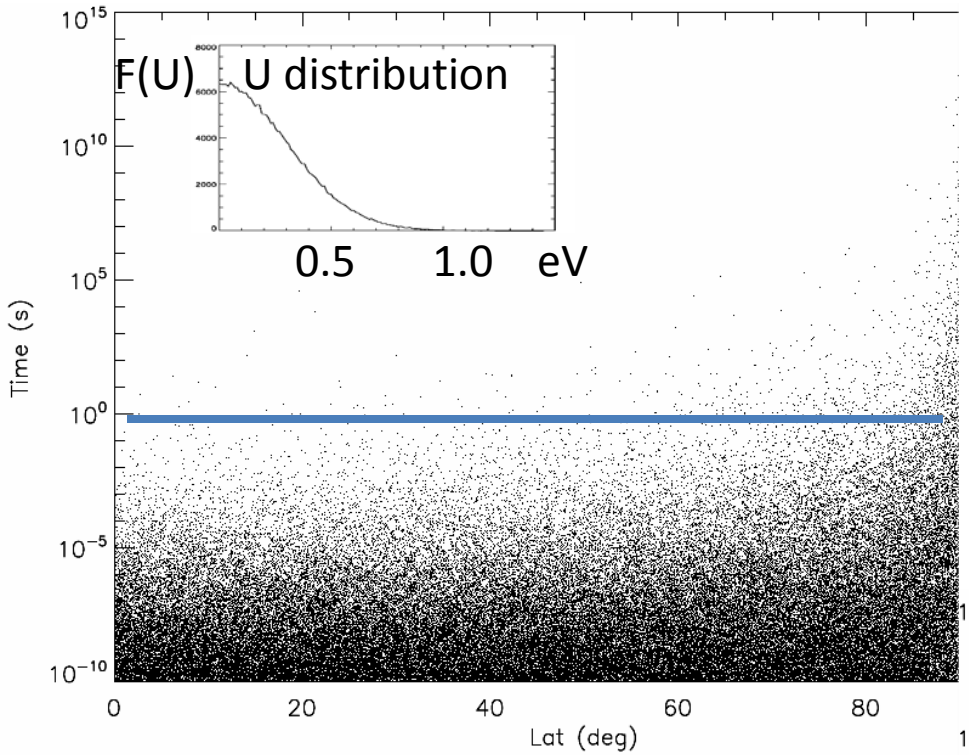


General trend: 1) Curved move vertically based in water in cloud

2) Curves flatten with less extreme temperature range

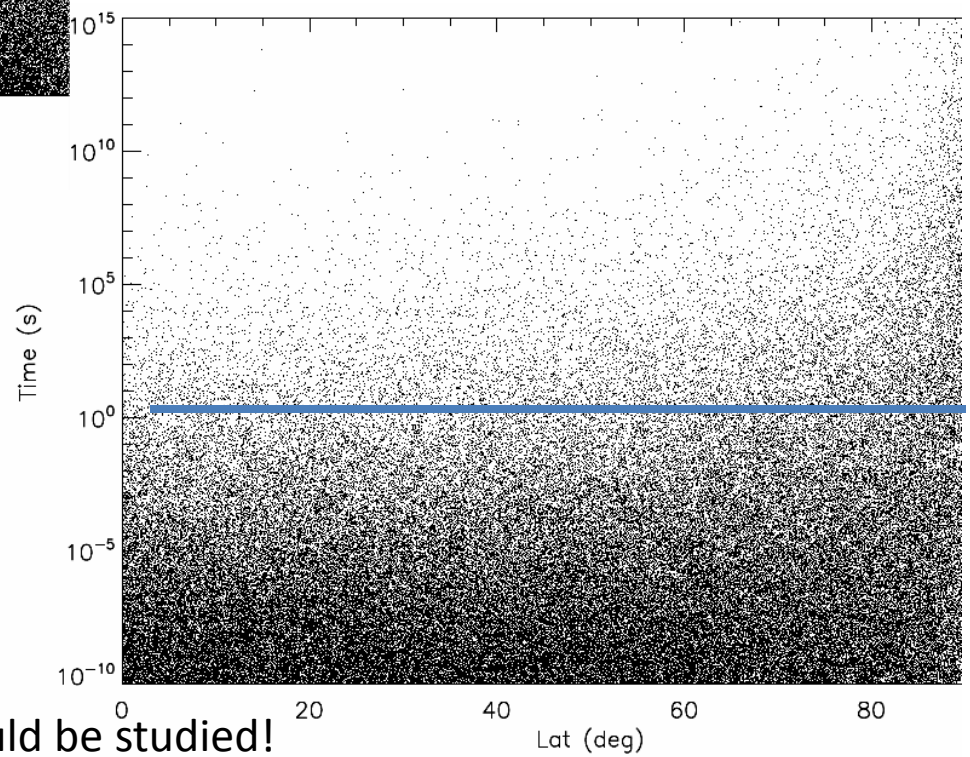
Key Takeaway: Temperature is important, but U(defects) are the defining variable

Example Distributions of U



$U_w = 0.3$ eV

Some waters 'stick' above ~ 45 deg lat



$U_w = 0.5$ eV

Many more waters 'stick' in a defect-rich/weathered surface

We really don't know this distribution…should be studied!

Asteroid Defect Garden

- Given Orion water source, visiting astronauts could perform a set of adsorption studies on various altered regolith at the Asteroid
  - Lightly overturned regolith (pristine)
  - Regolith with recent fractures
  - Regolith undergoing laser ablation to mimic impacts
  - Place surfaces of known material in garden

  - Test idea that defects are strong controlling element
  - Analogous to the Long Duration Exposure Facility

Conclusion

- **Key Takeaway #1:** Orion is a source of water and will likely be the dominant exosphere
- Water residency time/'sticking' time defined by the Polanyi-Wigner equations [Poston et al., 2013]
- Water surface 'sticking' can be high in a defect-rich surface…approach a monolayer
- **Key Takeaway #2:** Controlling variable in adsorbing the water is **weathering** and the distribution of **defects**, with temperature a secondary variable.
- Surface water content varies from 10^5 m^{-2} to10^{20} m^{-2} depending upon surface weathering & defects
- Controlling element U/T with broad range of U.
- To get an nature of U (defects), build a 'Defect Garden'?
- **Key Takeaway #3:** Avoid doing water dumps near asteroid!

Backup

Value of Activation Energy, U

- Cannot really pick a single U value
- In reality, likely have a distribution of Us that is representative of the variation of defects and irregularities in the surface lattice
- Distribution of U values has an average U value, <U>, and width, U_w…lends itself to a Monte Carlo approach
- **Model:** N = 240000 water adsorptions from high to low latitudes assigning each an individual U value that is part of a Gaussian distribution of activation energies representative of the variation in crystal irregularities
- Calculated residency or 'sticking' time
- Assume many adsorption sites with low U (regular crystal lattice) and progressively decreasing number with increasing U (more defected lattice)