Photodesorption of Ices

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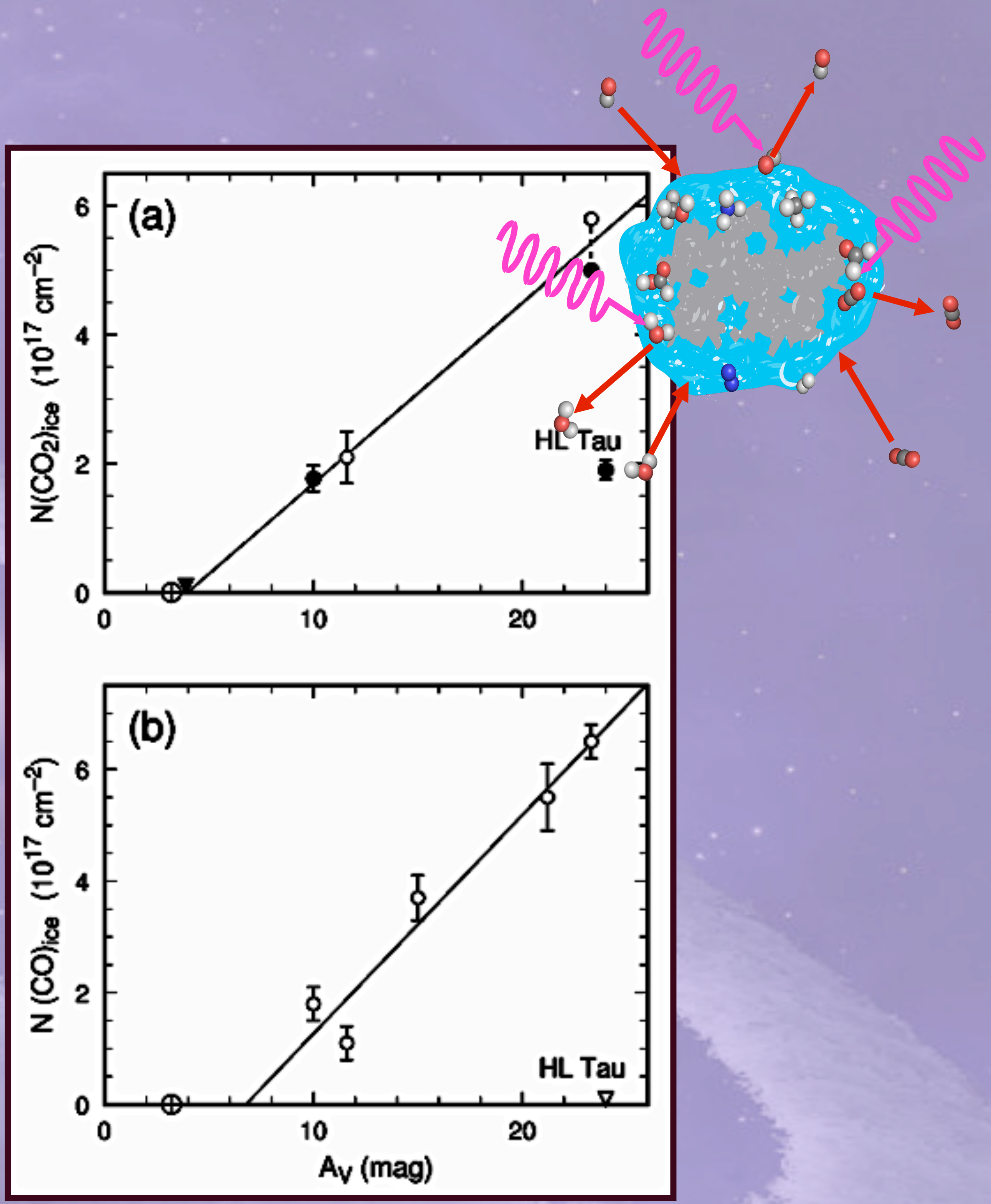
Ice desorption at cloud and disk edges

- ★Excess H_2O at cloud edges
- ★Observed delayed freeze-out of H_2O and CO_2 at outer few A_V of clouds
- ★Cold HCO_2^+ in clouds and towards a protostar
- ★Cold CO gas in proto-planetary disks
- ★Cold H_2O observations possible in disks with Herschel



Bergin et al. 2005

Previous photodesorption estimates

★CO

★Estimates based on theory and experiments on noble gases

★10^{-8} - 10^{-5} photon^{-1}

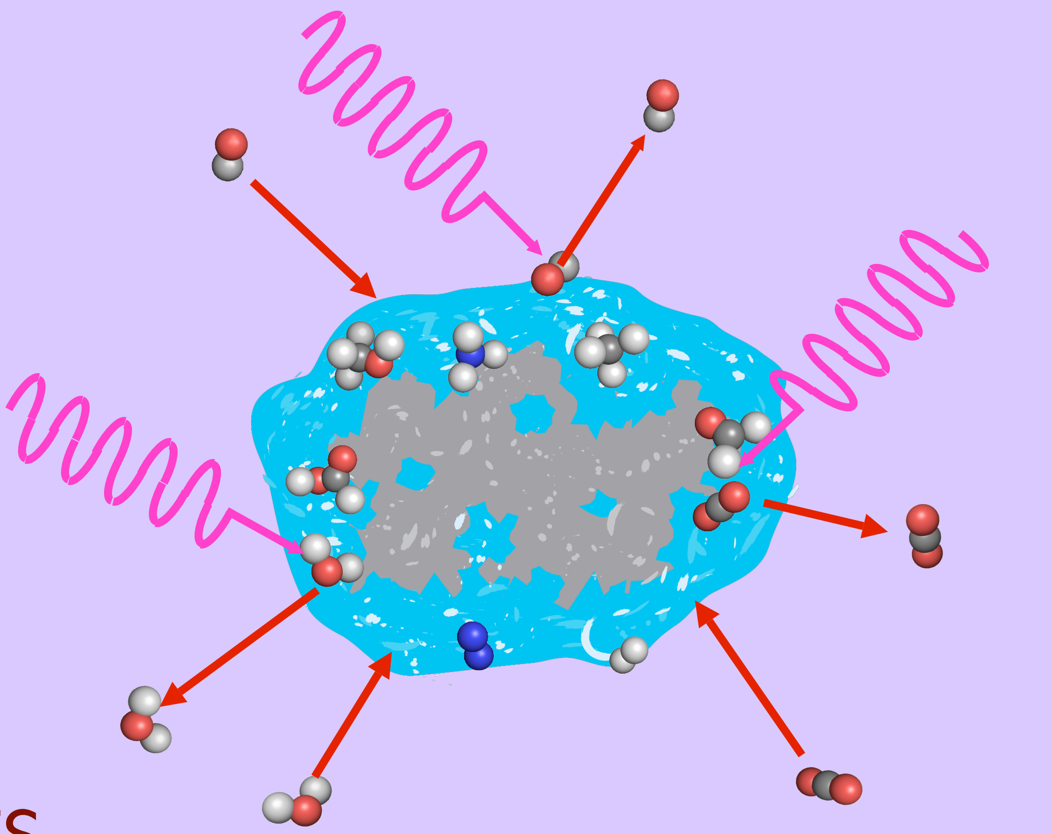
★H_2O

★Estimates inferred from experiments and observations of cloud edges

★10^{-4} - 10^{-2} photon^{-1}

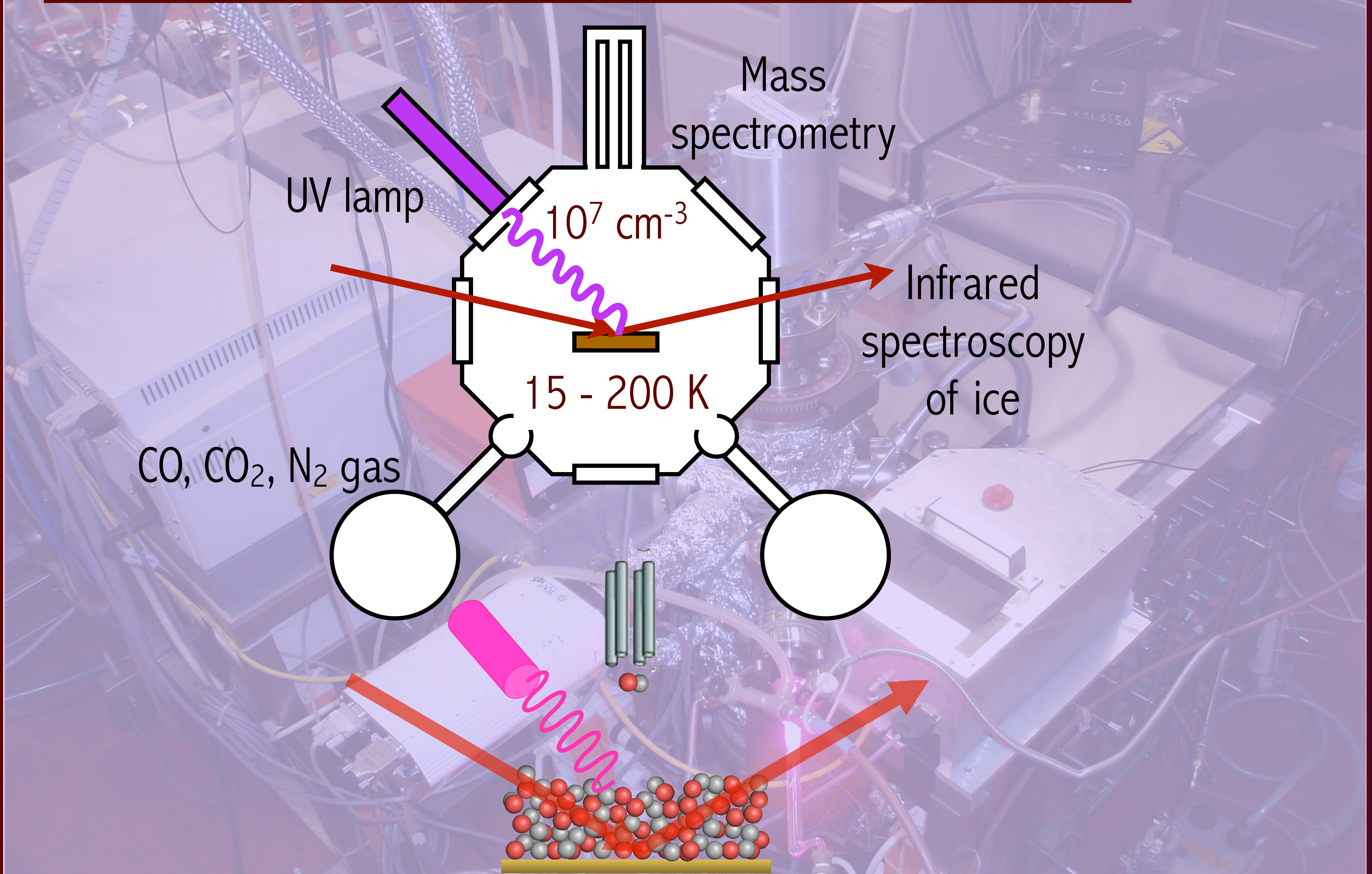
★CO_2

★No estimates



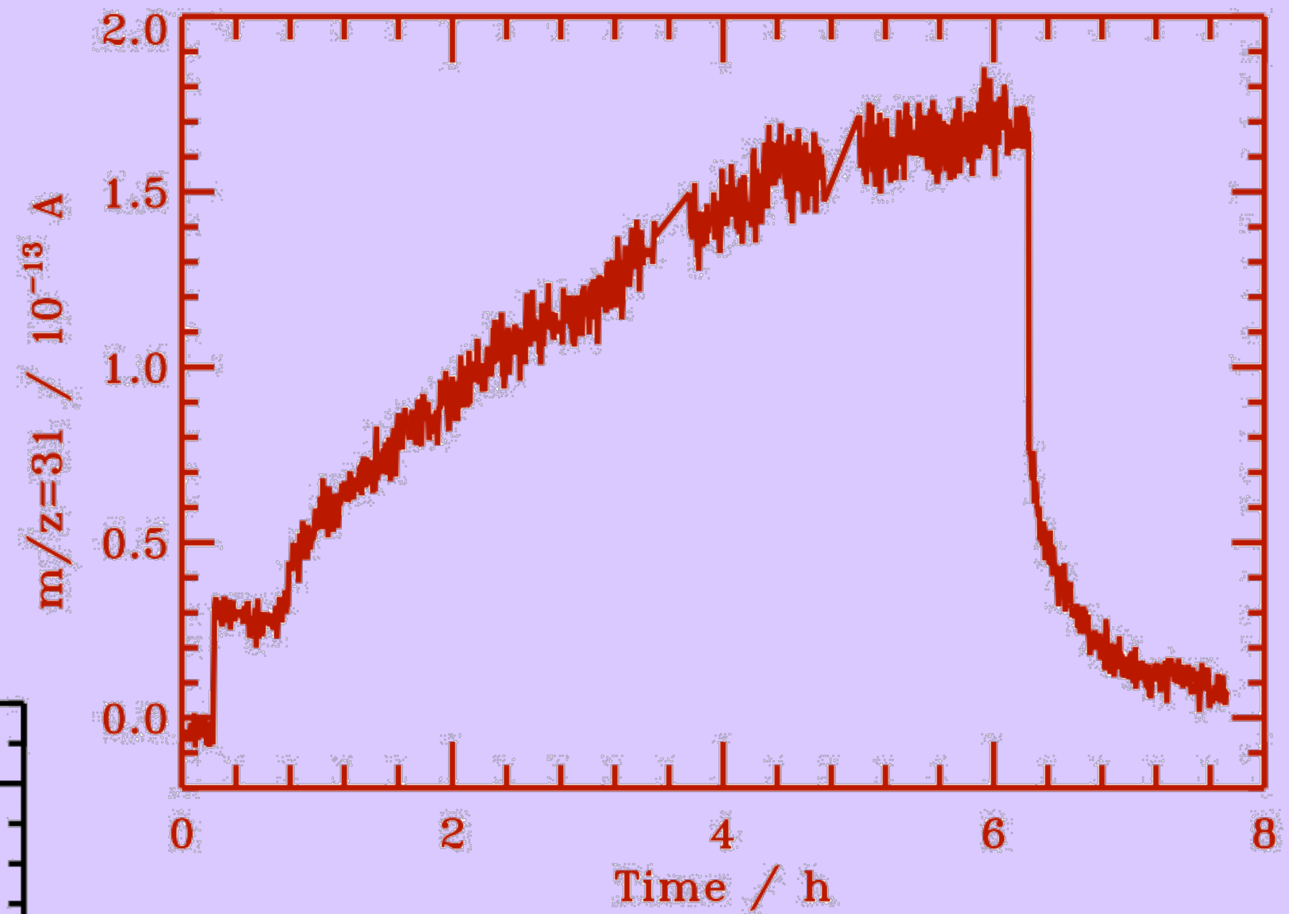
Hartquist & Williams 1990, Melnick et al. 2005, Westley et al. 1995

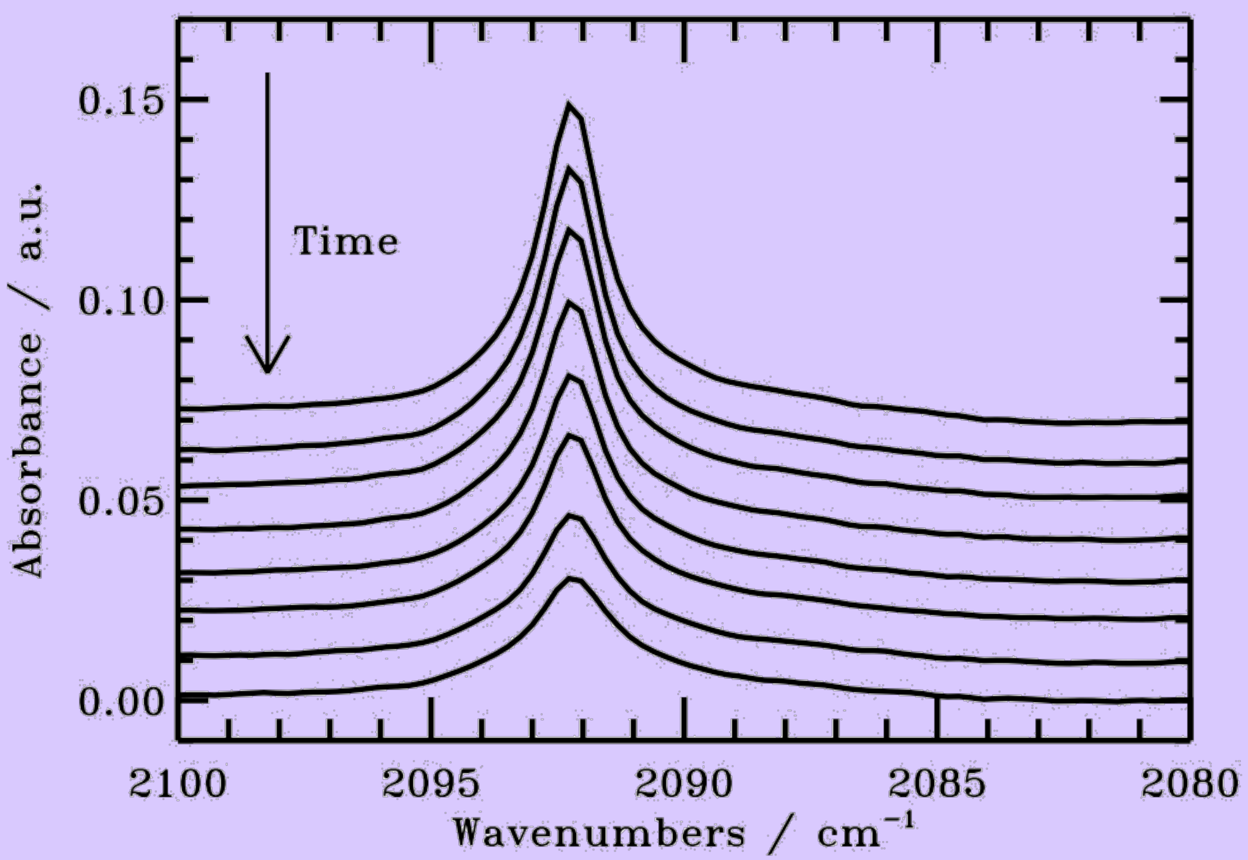
Photodesorption in the laboratory



Photodesorption in the laboratory

Total photodesorption rate from RAIRS



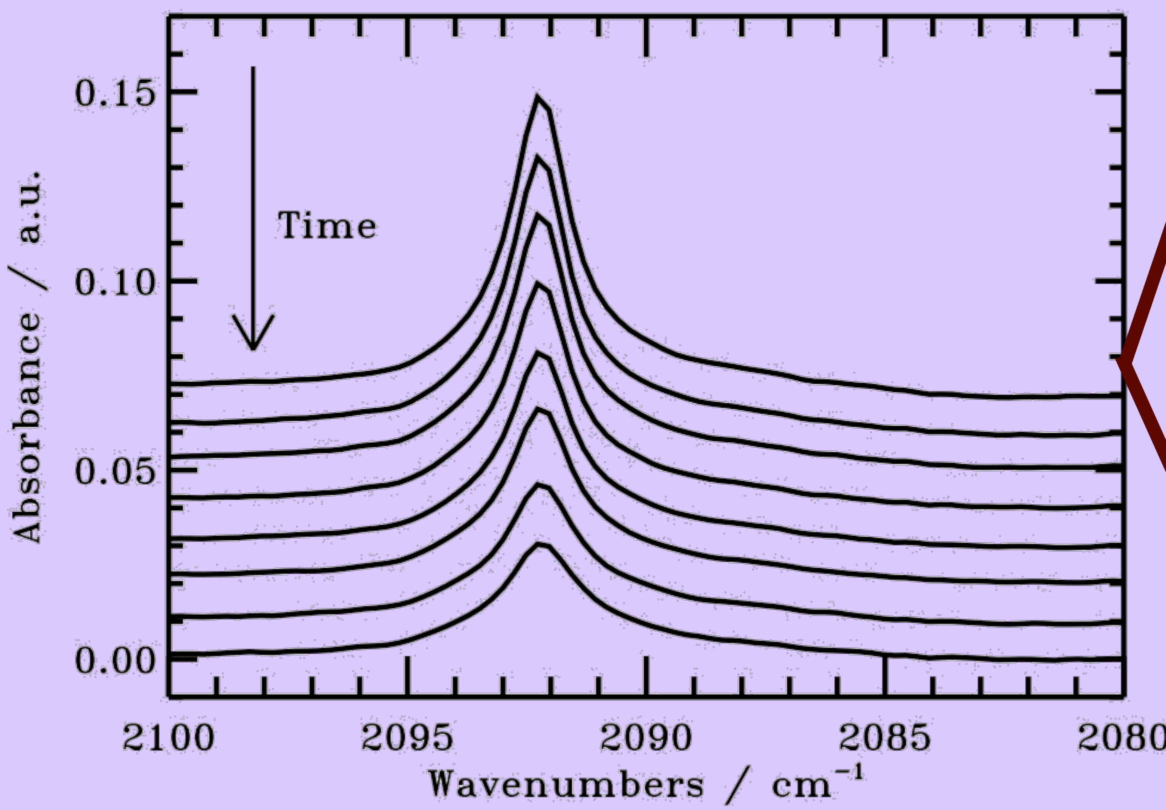


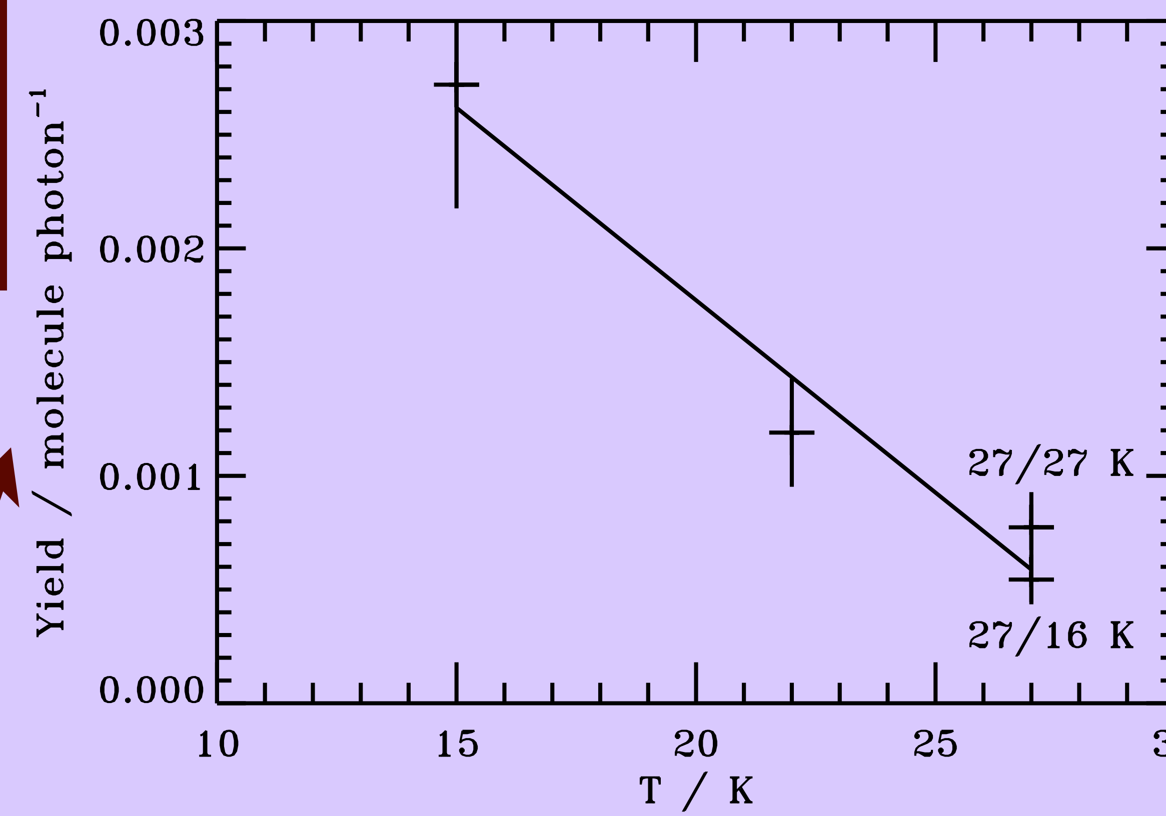
Relative photodesorption rates from QMS: CO-from-CO_2, OH-from-H_2O, H_2O-from-H_2O

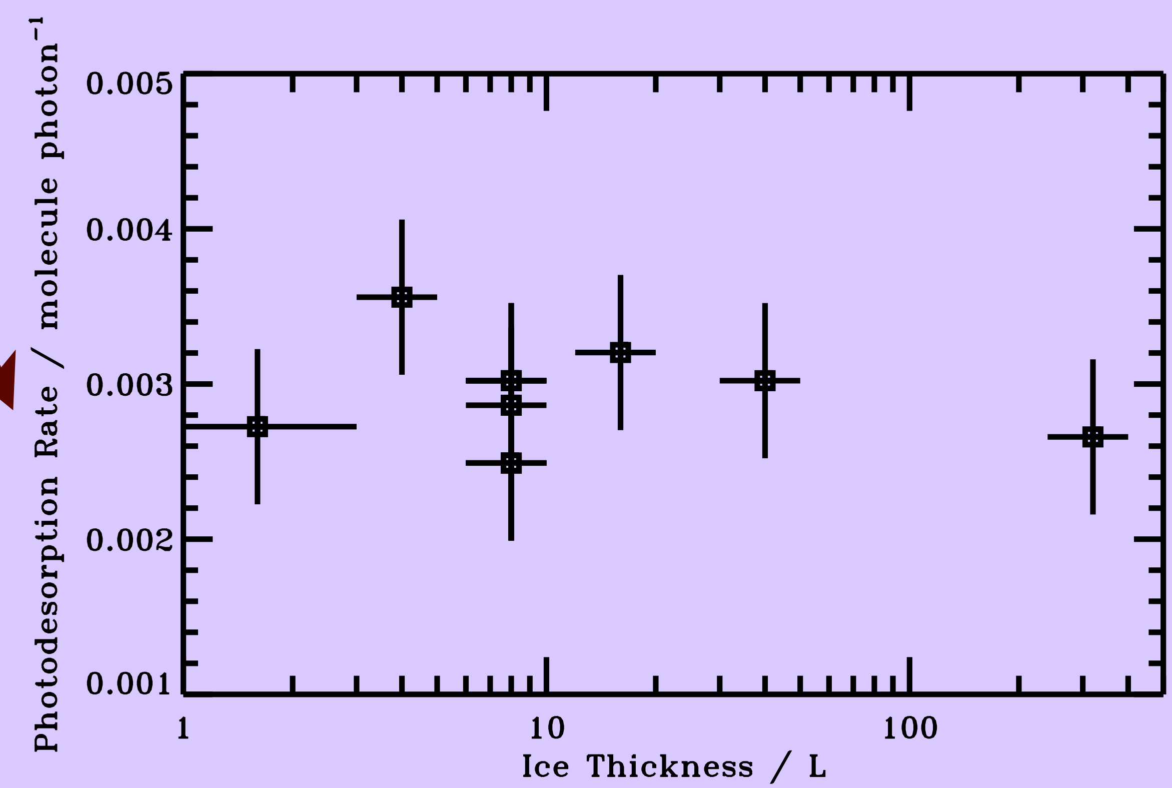
CO photodesorption:

Ice destruction =
ice desorption

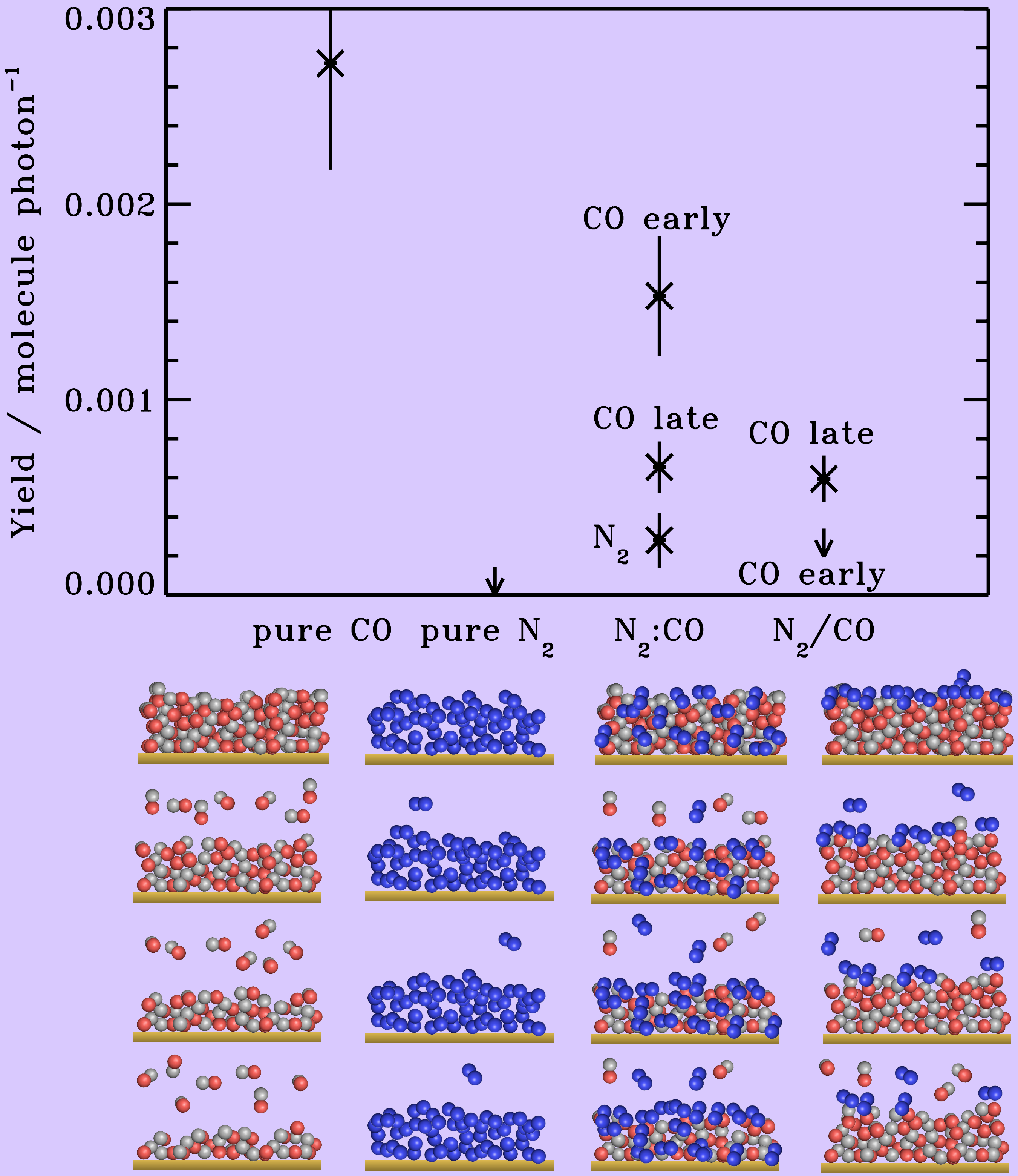
Öberg et al. 2007





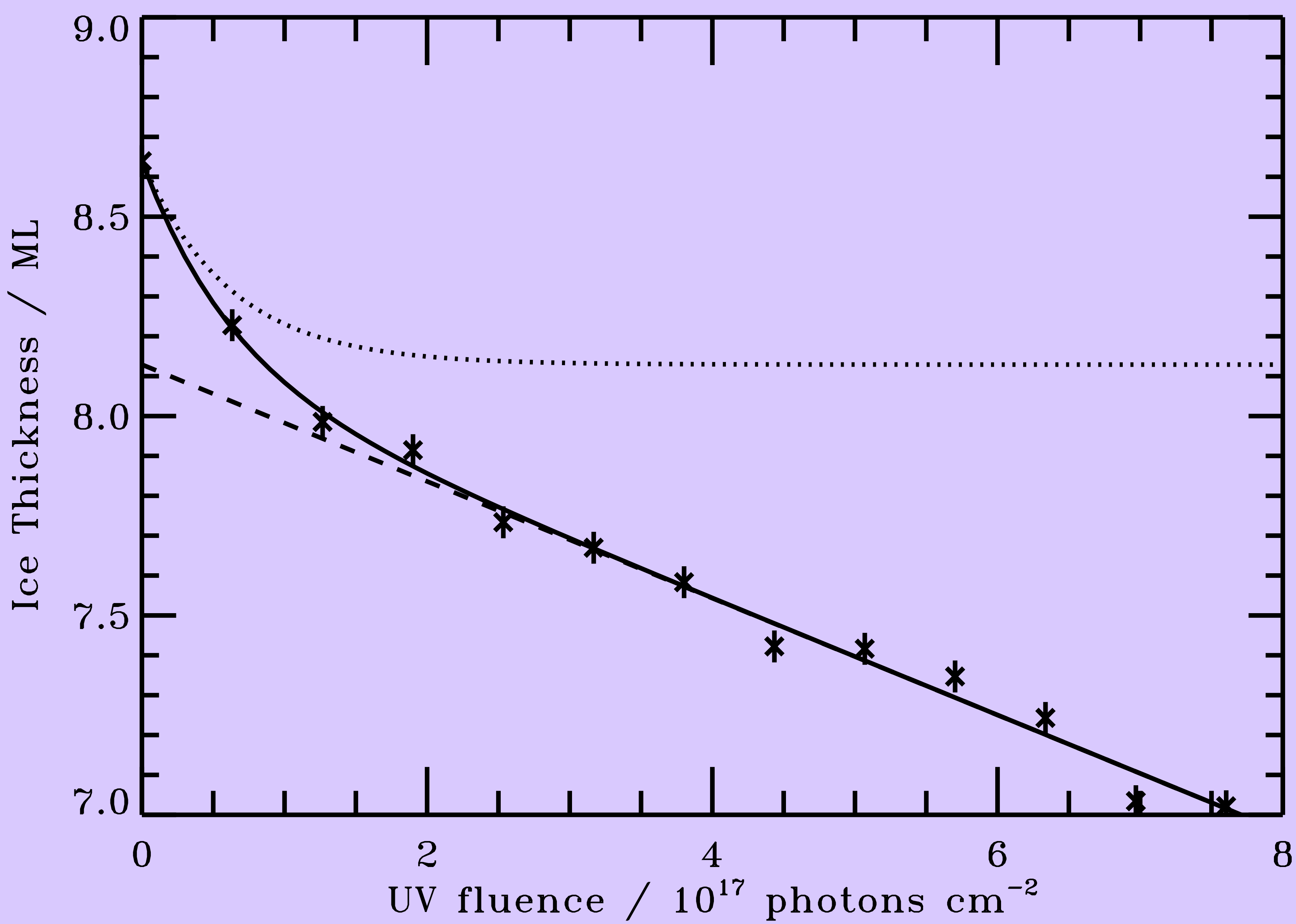


CO + N_2 photodesorption



- ★CO desorption is efficient: 2.7×10^{-3}
- ★Pure N_2 desorption is slow: $< 2 \times 10^{-4}$
- ★CO desorption only from surface layer
  - ★Explains thickness independence
  - ★Explains mixed experiments
  - ★Explains T dependence

Deriving H_2O photodesorption:
0th vs. 1st order reactions

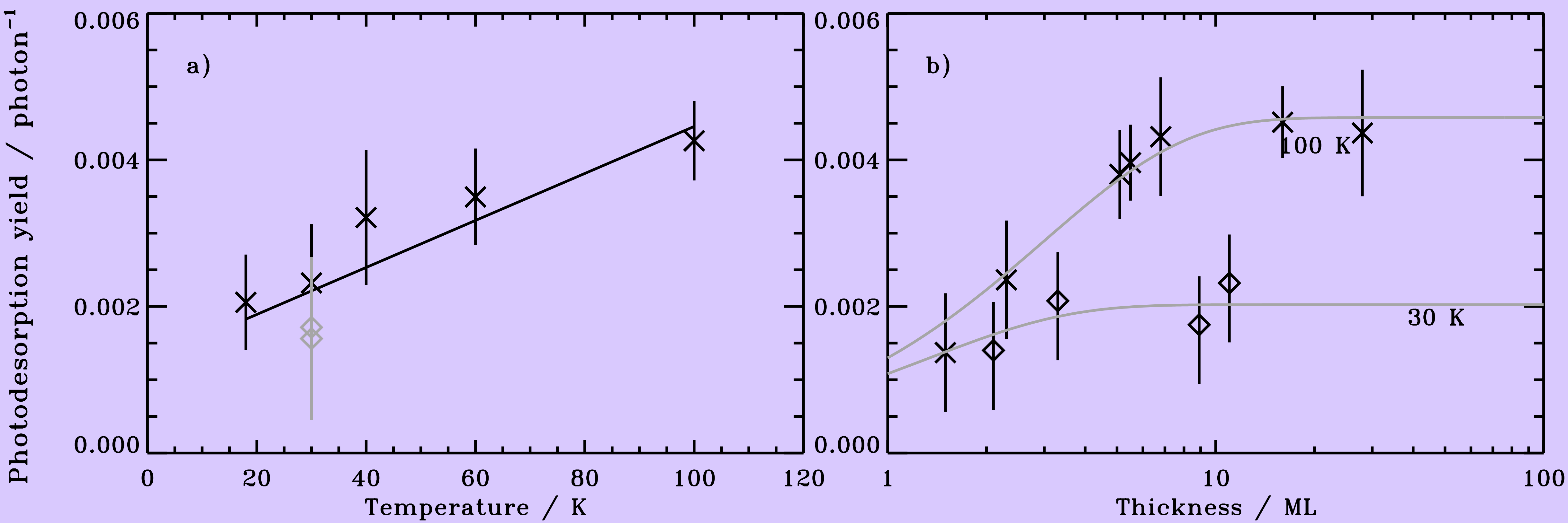


Have to separate photo-chemistry and photo-desorption

Use different kinetics of surface and bulk reactions

Öberg et al. submitted to ApJ

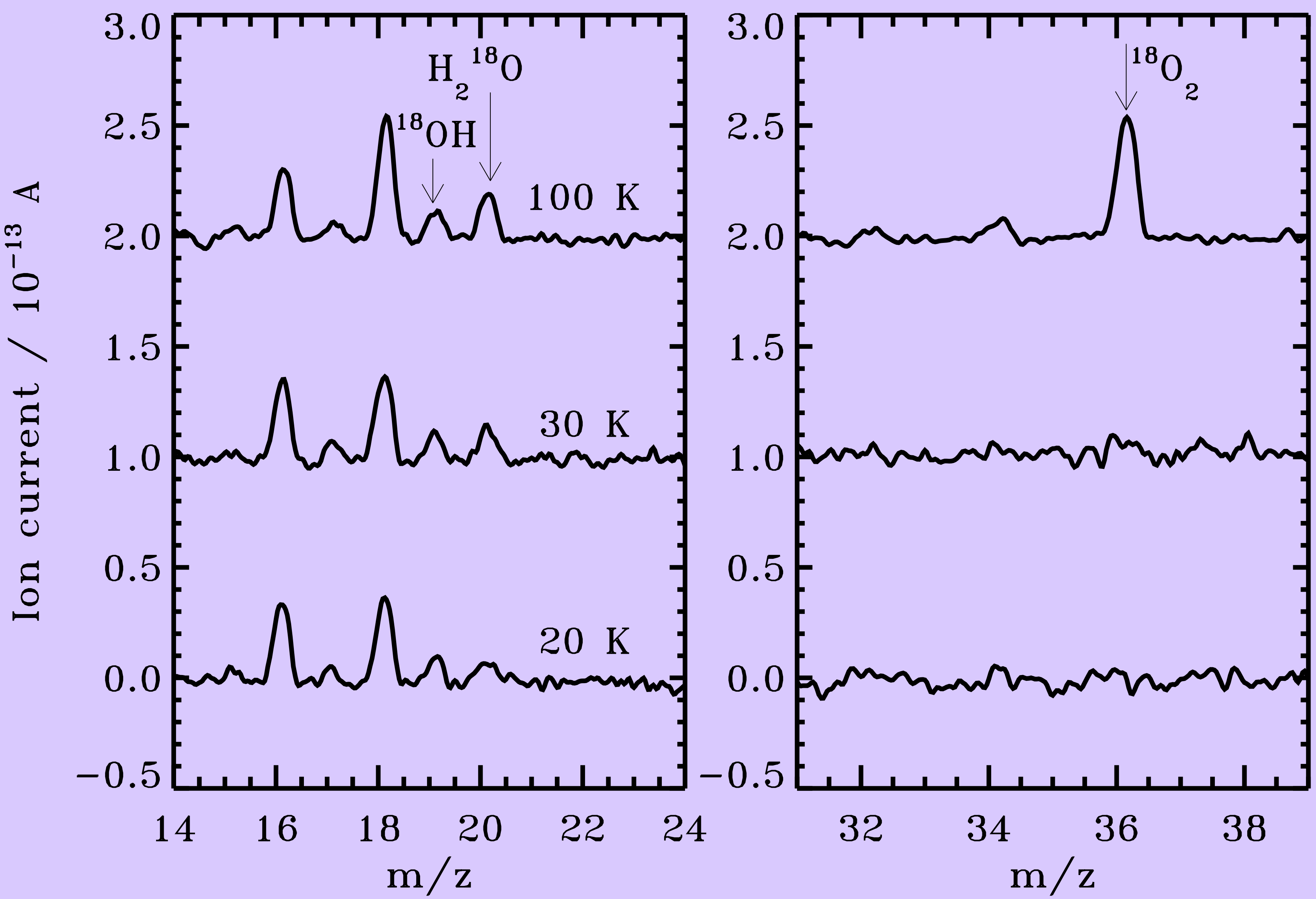
Deriving H_2O photodesorption:
The total yield



- ★Total photodesorption rate at 100 K: ~4 x 10^{-3} photon^{-1}
  - ★8 x 10^{-3} photon^{-1} in Westley et al.
- ★No dependence on flux, time or photon fluence
- ★Total yield is thickness and temperature dependent

Öberg et al. submitted to ApJ

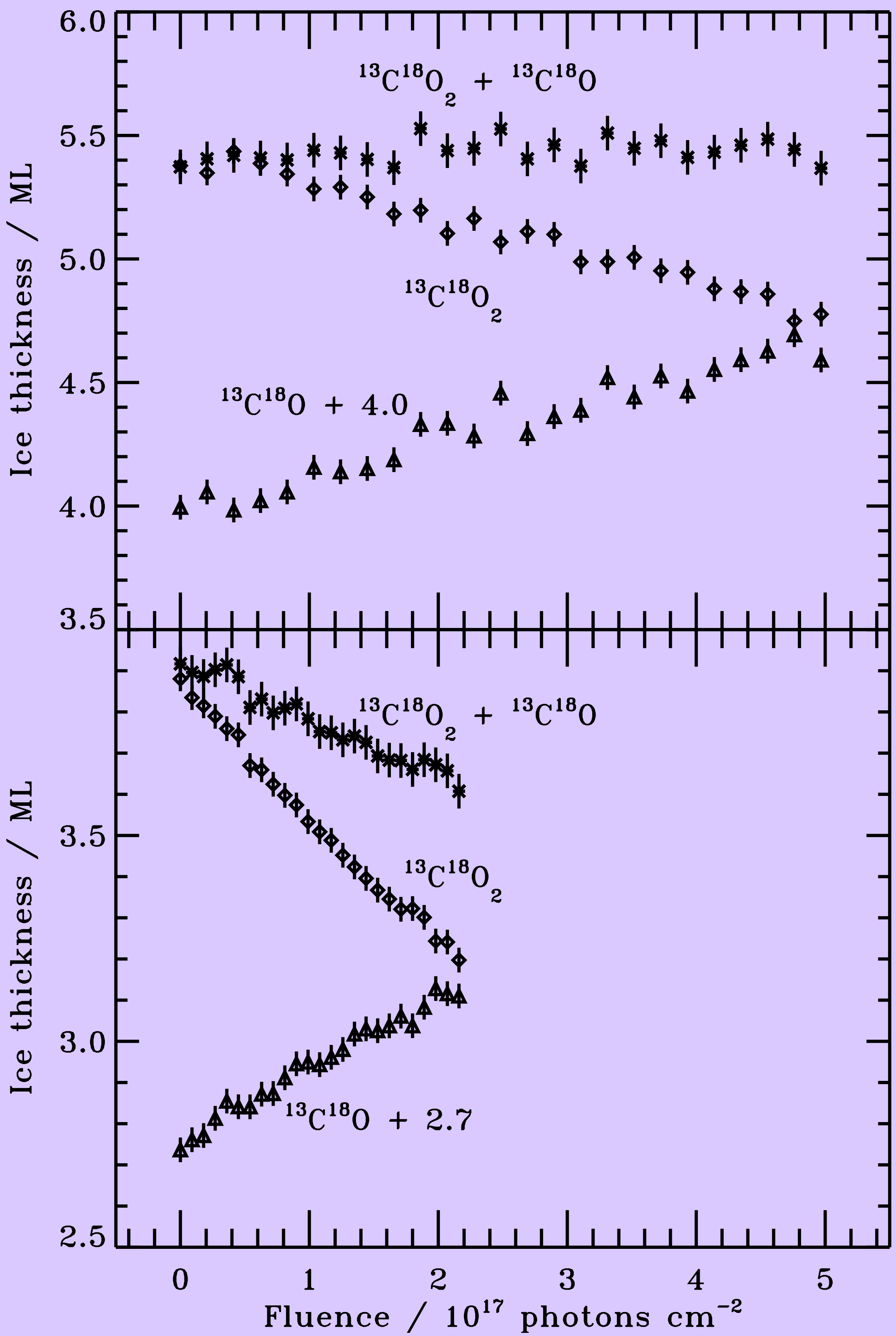
Deriving H_2O photodesorption:
Photodesorption products



Temperature dependence of photo-desorption products: H_2O, OH and O_2

Öberg et al. submitted to ApJ

Deriving CO_2 photodesorption:
Mass balance calculations

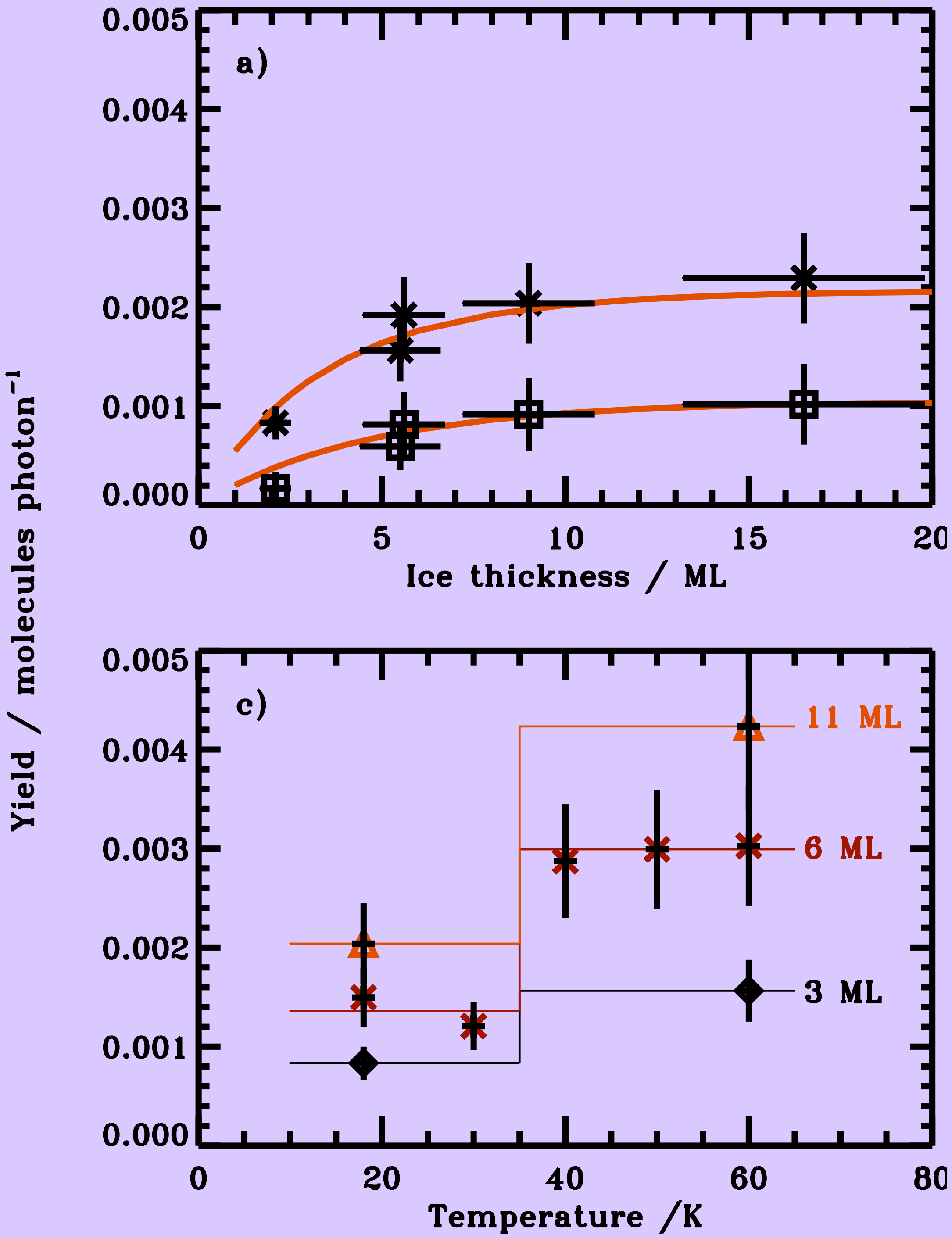


Have to separate photo-chemistry and photo-desorption

Compare lost CO_2 with major formation product - CO

Öberg et al. submitted to A&A

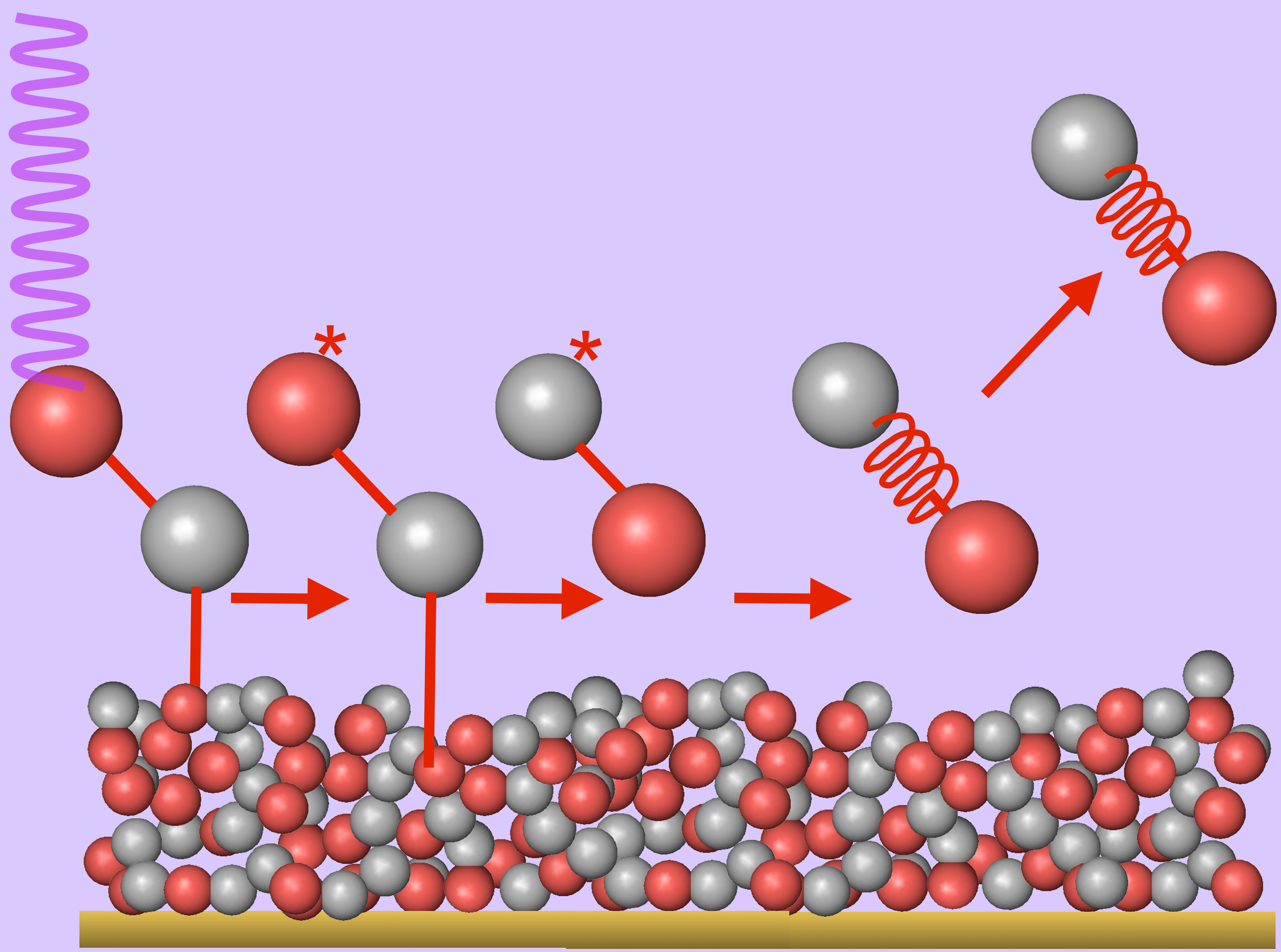
Deriving CO_2 photodesorption:
Mass balance calculations



- ★Similar to H_2O dependencies
- ★Can separate CO and CO_2 desorption products
- ★For both H_2O and CO_2 increased temperature increases ice diffusion, which increases the desorption yield
- ★Sub-monolayer desorption inferred from model of multi-layer desorption

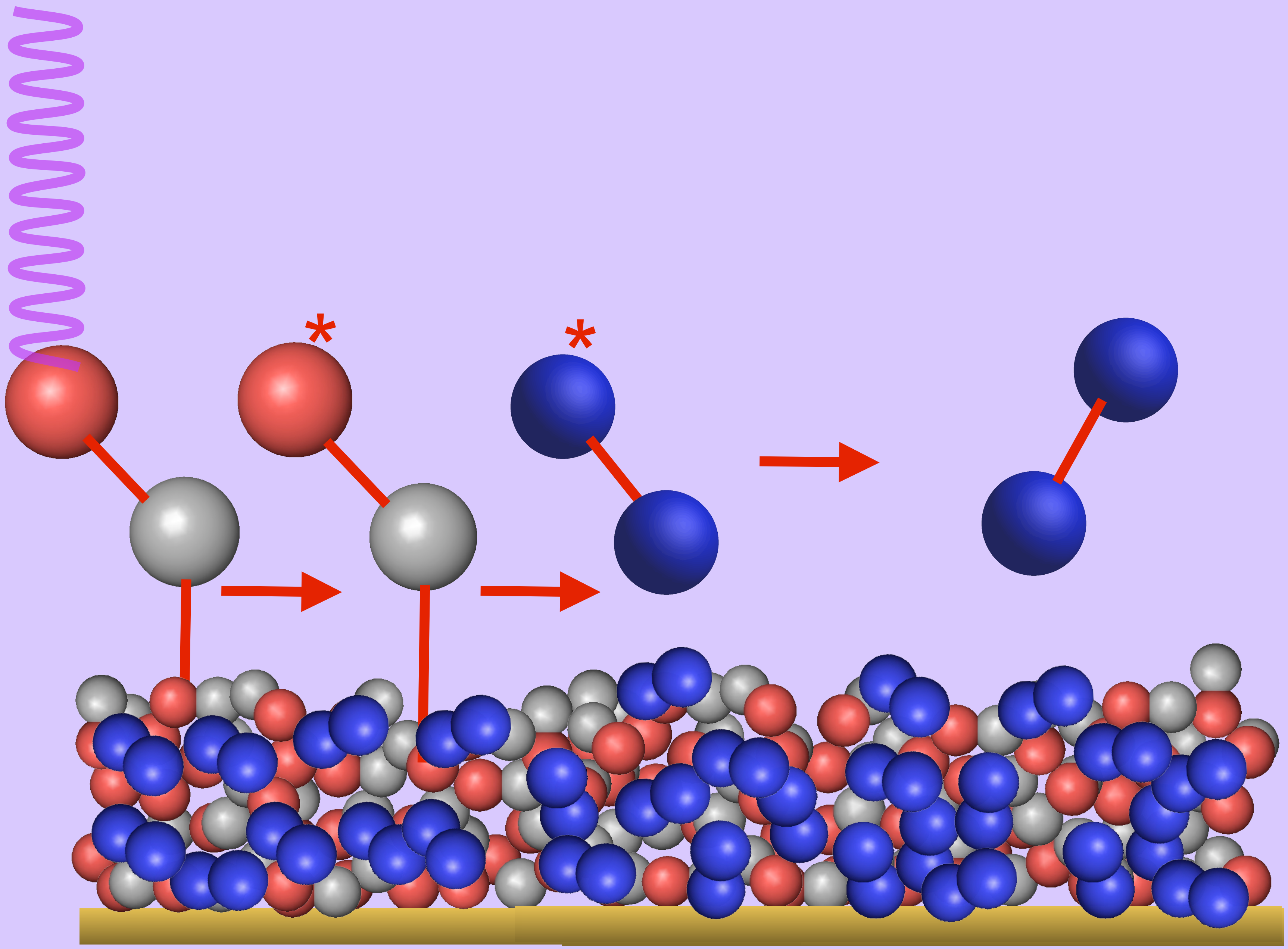
Öberg et al. submitted to A&A

Surface photodesorption of CO ice



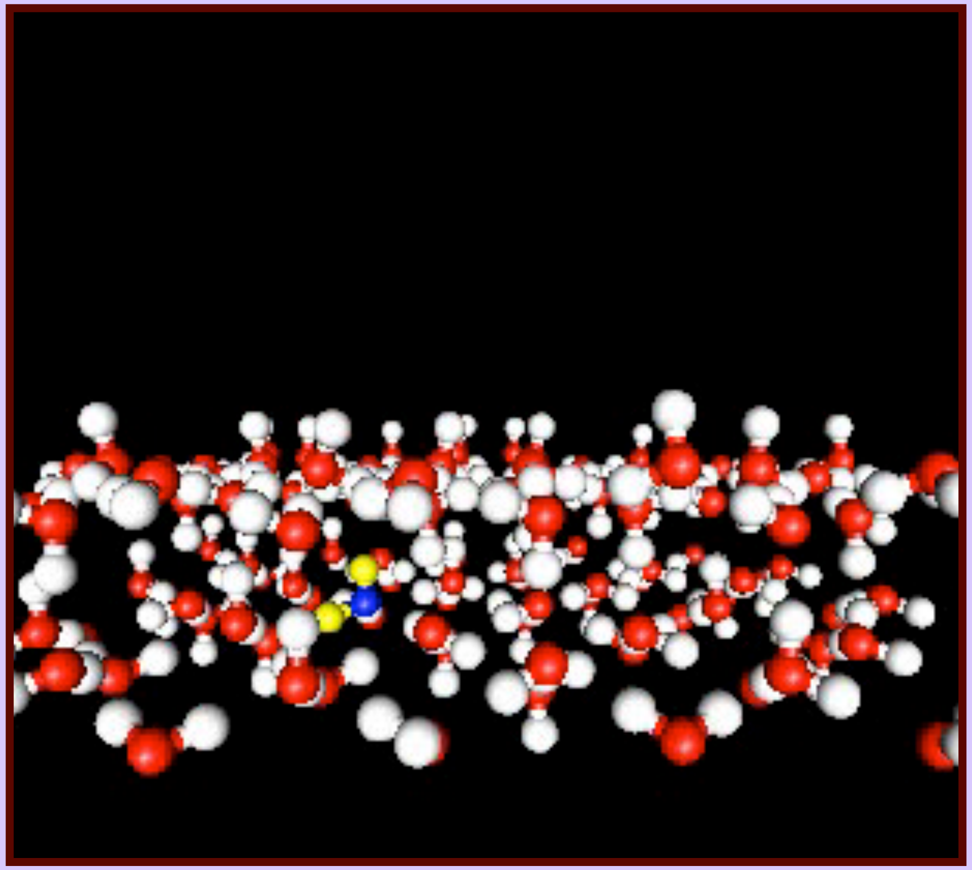
Öberg et al. 2007, Takahashi & van Hemert in prep.

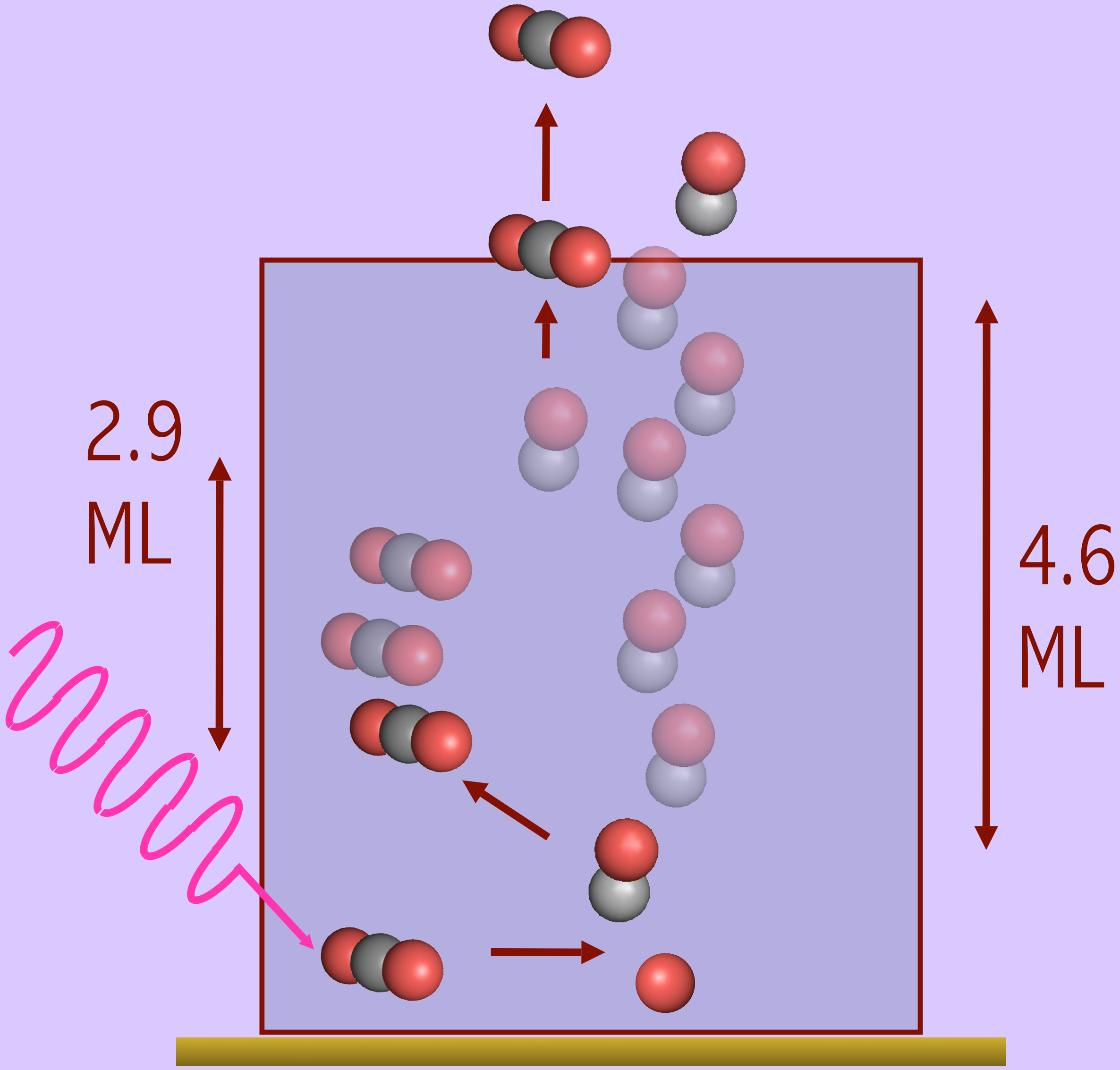
Co-photodesorption of N_2 ice



Öberg et al. submitted to A&A, Takanashi & van Hemert in prep.

Dissociation and desorption of H_2O and CO_2

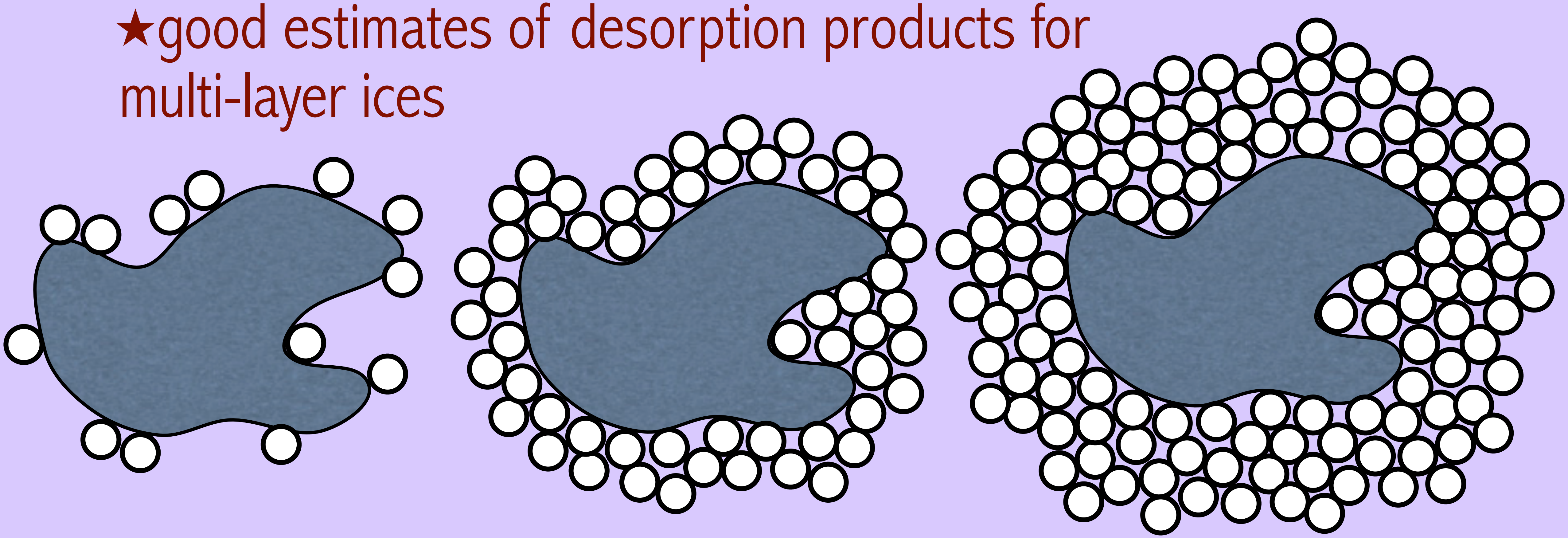




Andersson et al. 2008, Öberg et al. submitted to ApJ

Photodesorption in astrochemical models

- ★1st vs. 0th order vs. in between
    - ★dependent on ice coverage
- ★Cloud edges vs cloud cores
    - ★in the lab always start with multilayer
    - ★in clouds build up ice from sub-monolayers
    - ★good estimates of desorption products for multi-layer ices



Photodesorption rate equations

★Cloud edges:

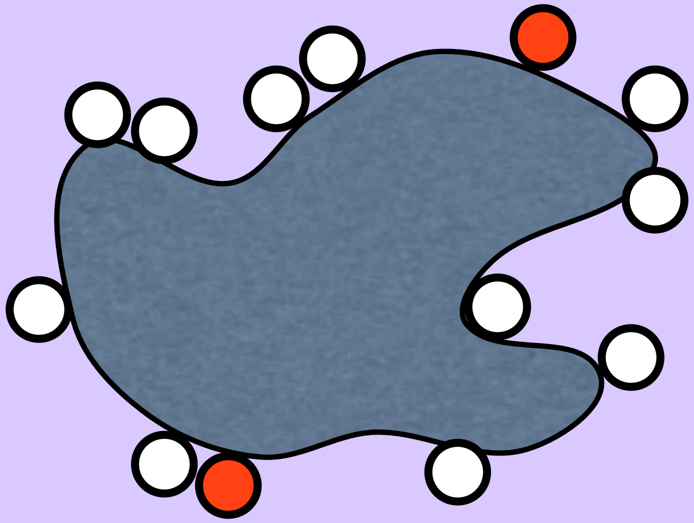
$$R_{\mathrm{CO}} = 10^{-3}\left(2.7 - (T - 15) \times 0.17\right) \times \sigma_{\mathrm{gr}} f_{\mathrm{CO}} I_{\mathrm{UV}} \times x$$

$$R_{\mathrm{CO_2}} = \left(0.6 \times 10^{-3}\right) \times \sigma_{\mathrm{gr}} f_{\mathrm{CO_2}} I_{\mathrm{UV}} \times x$$

$$R_{\mathrm{H_2O}} = \left(1.2 \times 10^{-3}\right) \times \sigma_{\mathrm{gr}} f_{\mathrm{H_2O}} I_{\mathrm{UV}} \times x$$

$$f_{\mathrm{CO}} = \frac{n_{\mathrm{CO(s)}}}{n_{\mathrm{ice}}}$$

$$x = \frac{n_{\mathrm{ice}}}{n_{\mathrm{gr}} \times n_{\mathrm{sites}}}$$



Photodesorption rate equations

★Build-up of ices 1<x<3 at 10 K, 1<x<10 at T>30 K:

$$R_{\mathrm{CO}} = 10^{-3}\,(2.7 - (T - 15) \times 0.17) \times \sigma_{\mathrm{gr}} f_{\mathrm{CO}} I_{\mathrm{UV}}$$

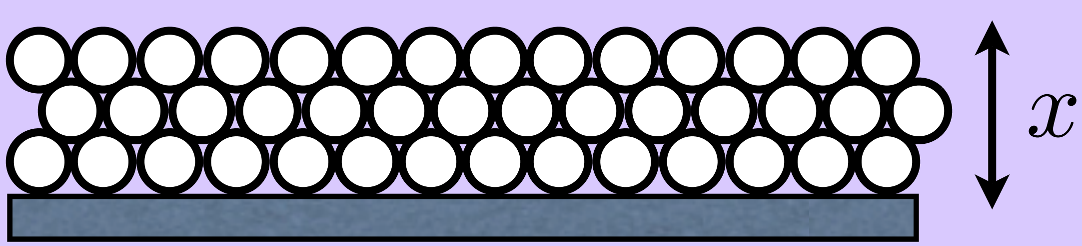
$$R_{\mathrm{CO_2}} = 10^{-3}\left(1.2(1 - e^{-x/2.9}) + 1.1(1 - e^{-x/4.6})\right) \times \sigma_{\mathrm{gr}} f_{\mathrm{CO_2}} I_{\mathrm{UV}}$$

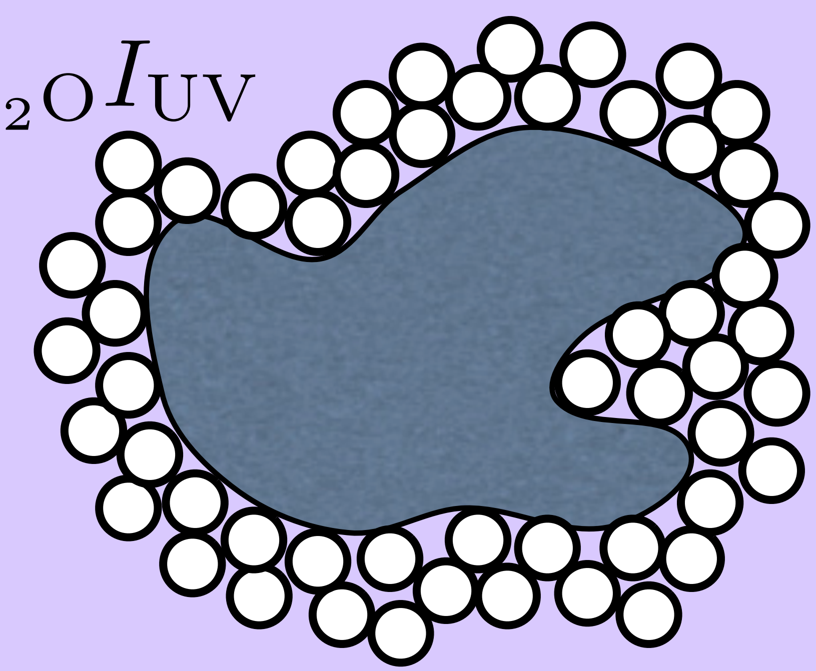
$$R_{\mathrm{H_2O}} = 10^{-3}\left((1.3 + 0.032 \times T)(1 - e^{-x/l(T)})\right) \times \sigma_{\mathrm{gr}} f_{\mathrm{H_2O}} I_{\mathrm{UV}}$$

★Cloud cores:

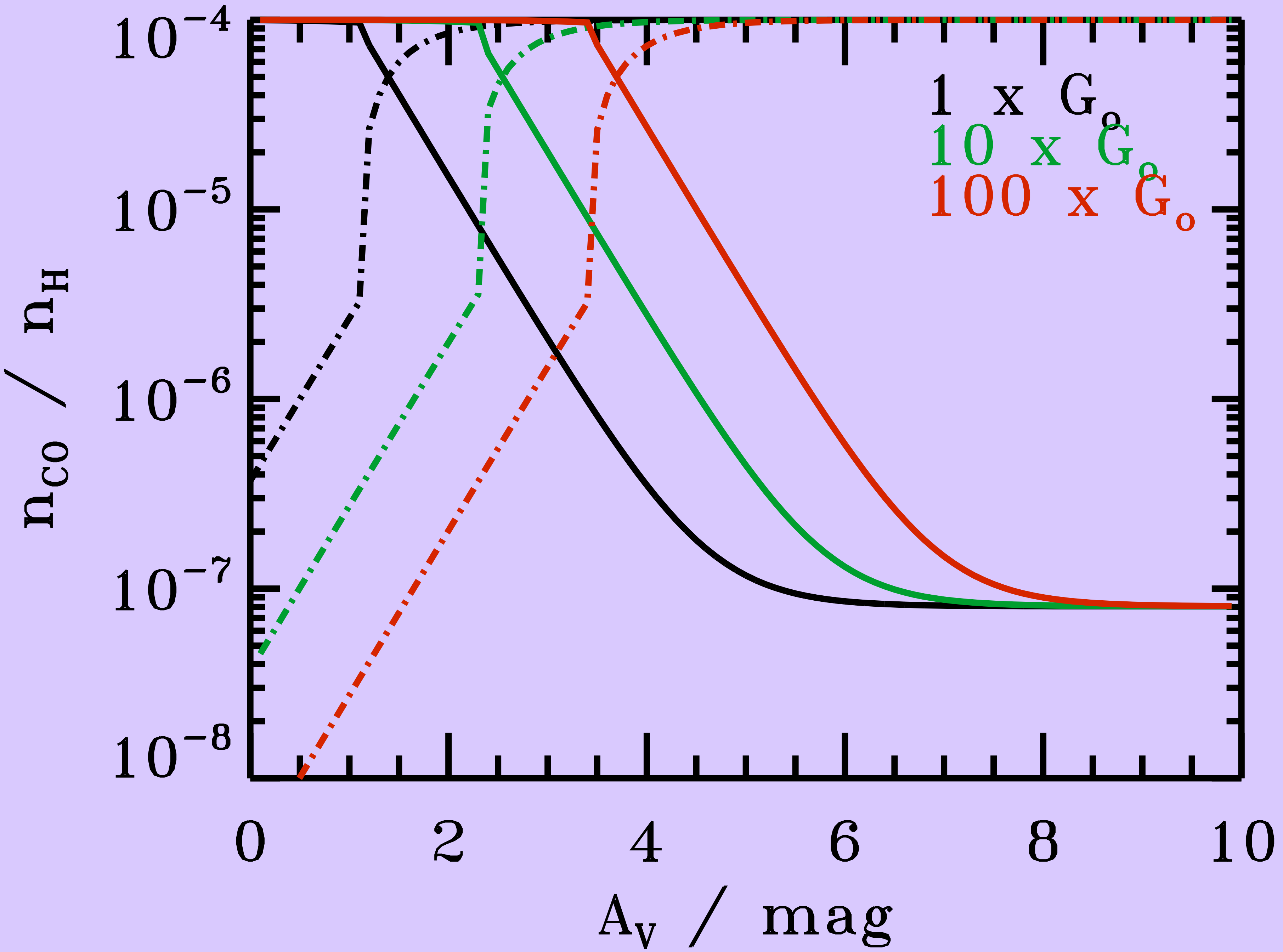
$$R_{\mathrm{CO_2}} = (2.3 \times 10^{-3}) \times \sigma_{\mathrm{gr}} f_{\mathrm{CO_2}} I_{\mathrm{UV}}$$

$$R_{\mathrm{H_2O}} = 10^{-3}\,(1.3 + 0.032 \times T) \times \sigma_{\mathrm{gr}} f_{\mathrm{H_2O}} I_{\mathrm{UV}}$$

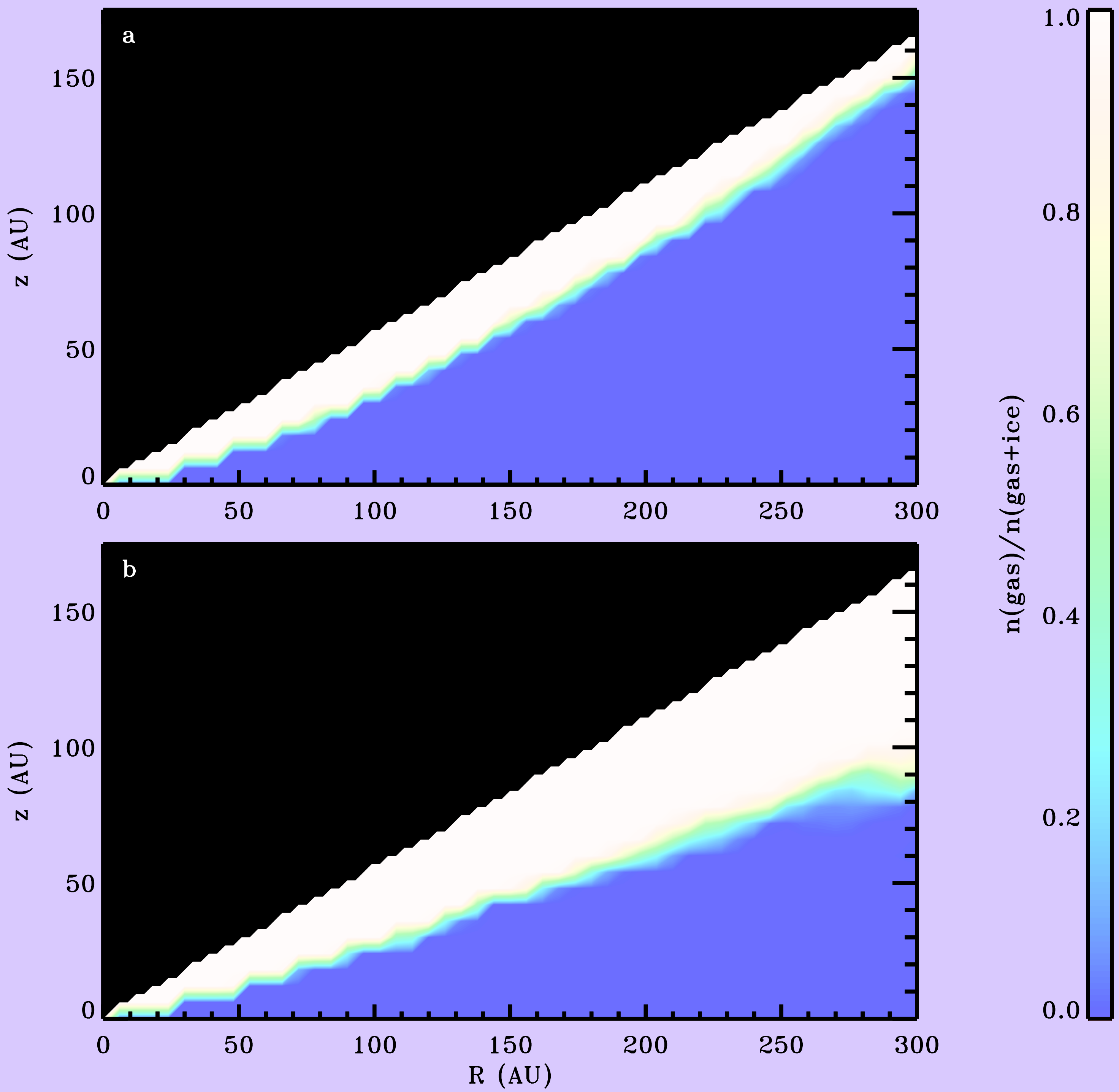




Consequences for cloud cores: CO



Consequences for disks: H_2O



Model of H_2O gas to gas+ice ratio in pre-main sequence star and disk without and with photo-desorption turned on.

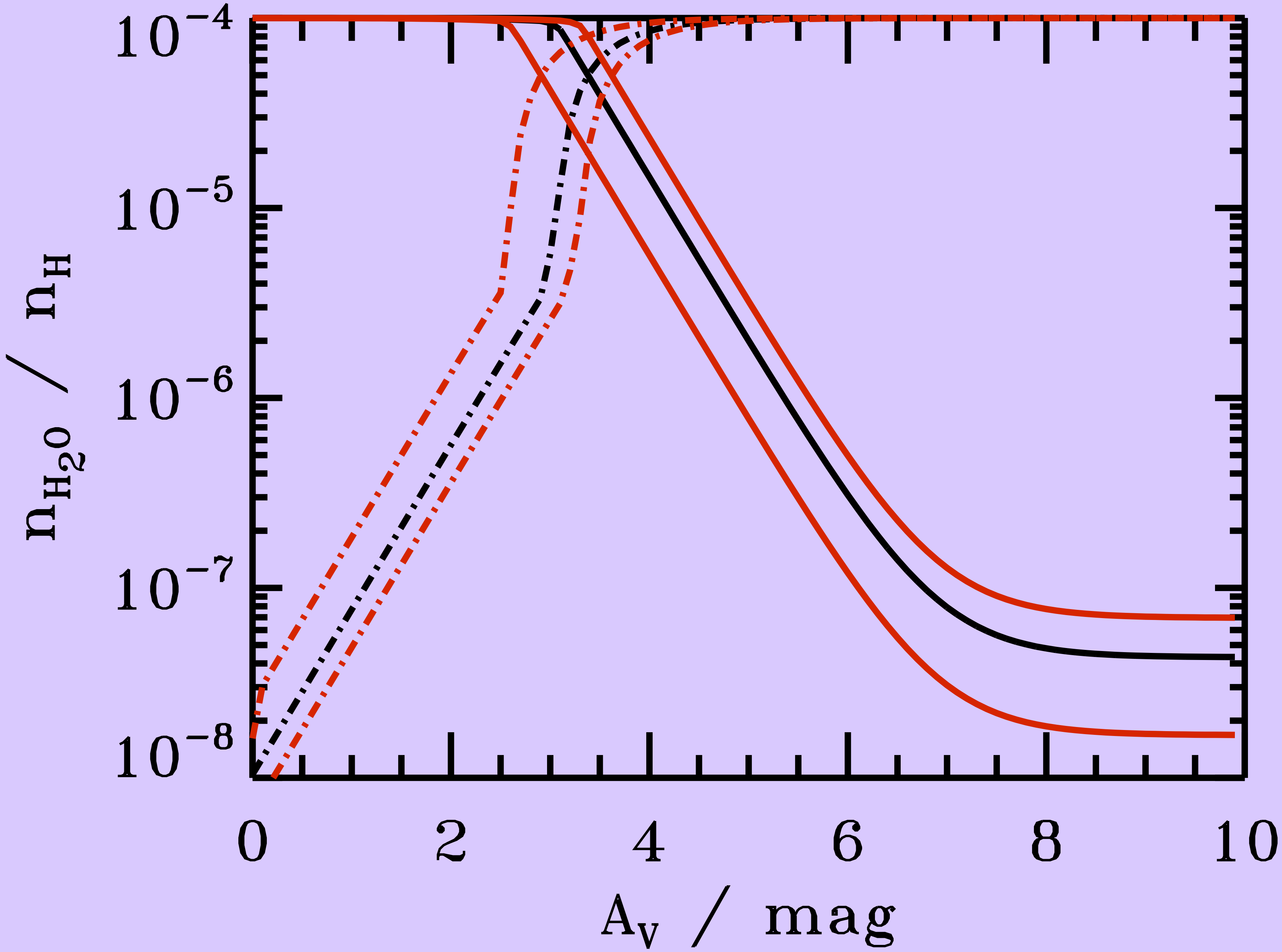
Photodesorption has a large impact on the gas chemistry, which should be easily detectable with Herschel

Uncertainties and ways to reduce them

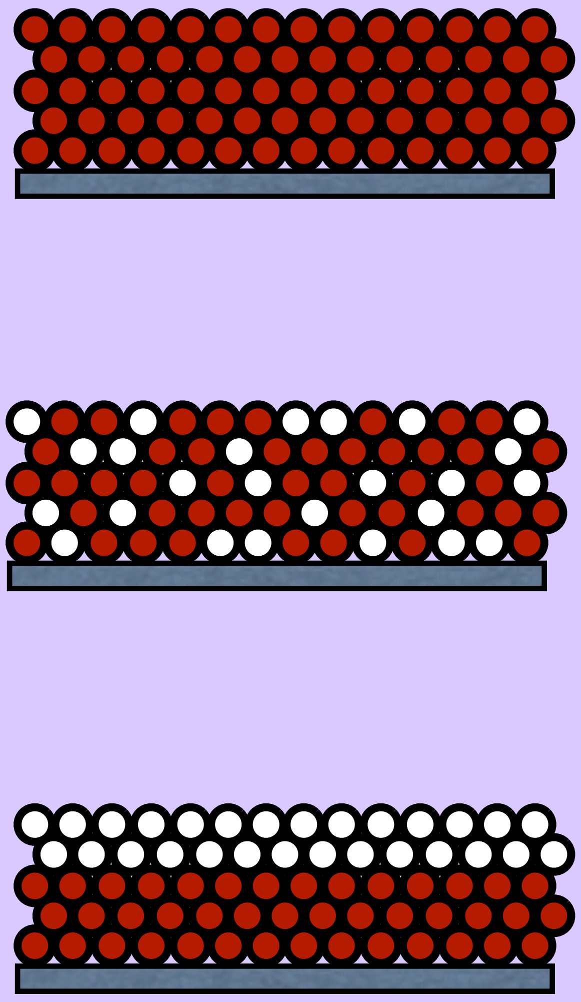
- ★Quantified uncertainties - factor of ~2
  - ★UV spectra, flux in lab - can be improved with current set-up
  - ★Ice loss rate - requires new set-up to be improved
- ★Quantifiable uncertainties
  - ★Pure vs. mixed vs. layered ices
  - ★UV spectra, UV flux and temperature structure in space
- ★Uncertainties that are difficult to quantify
  - ★Ice structure in space vs the lab
  - ★extrapolation to cloud and disk conditions - grain material and structure, UV flux (linear over 2 orders of magnitude)
  - ★total grain surface

Importance of uncertainties in models

Experimental uncertainties



Astrophysical uncertainties



Photodesorption experiments to come

- ★ $CO:H_2O$, $CO_2:H_2O$ and $CO:CO_2$ mixtures at 15 K
- ★ Monolayer of CO on gold, N_2 and H_2O at 15 K
- ★ Monolayer of H_2O on gold, N_2 and CO at 15 K
- ★ CH_3OH, CH_4 and NH_3 estimates