PostDoc Latvia
NACIONĀLAIS ATTĪSTĪBAS PLĀNS 2020
EIROPAS SAVIENĪBA
Eiropas Reģionālās attīstības fonds
IEGULDĪJUMS TAVĀ NĀKOTNĒ
VENTSPILS AUGSTSKOLA
VIRAC
Chemical effects of cosmic-ray induced heating of interstellar dust grains
Research application No. 1.1.1.2/VIAA/I/16/194

Temperature spectra for interstellar grains heated by cosmic rays (CRs)

Juris Kalvāns
(VIRAC)

Engineering Research Institute «Ventspils International Radio Astronomy Center» of Ventspils University College
Inženieru 101, Ventspils, Latvia, LV-3601

ABSTRACT
Recent data on cosmic ray (CR) intensity and spectra allows more precise estimates for the frequency f_T of CR impacts on interstellar grains that raise grain temperature T_{CR} to a particular extent. This frequency is an important parameter in astrochemistry that defines the rate of CR-induced surface molecule desorption and other heating-induced processes on the grains. We present detailed calculations of frequencies that indicate how often a grain reaches a certain temperature because of CR hits (i.e., temperature spectrum of CR-heated grains). We considered bare and ice-covered grains in interstellar molecular clouds suffering impacts by 30 CR species, whose spectra is attenuated by hydrogen column densities characteristic for starless and prestellar cores (Papers I and III). The more precise CR-induced grain heating frequencies are high and have to be tweaked to account for shielding by cloud gas and magnetic fields. We also present an initial estimate how the new frequencies affect the composition of interstellar clouds. The new data indicate an efficient CR-induced desorption that shapes the composition of interstellar ices in dense cores and keeps a fraction of volatile species in the gas phase in more diffuse regions.

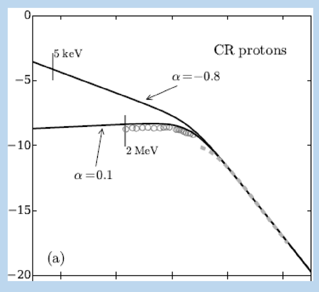
INTERACTION OF COSMIC RAYS WITH INTERSTELLAR GRAINS

WHOLE-GRAIN HEATING (WGH)

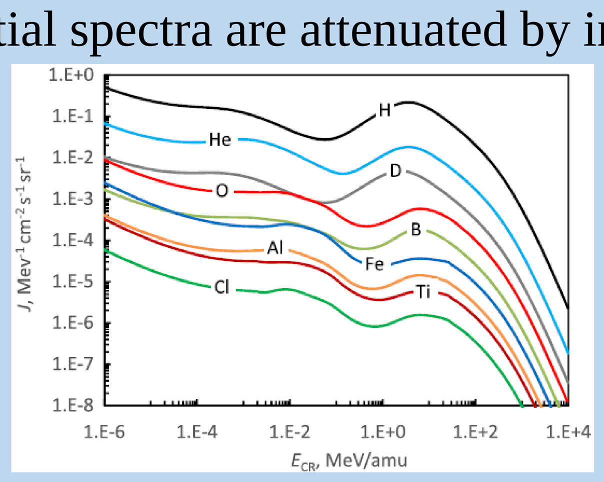
Problem: current astrochemical models use WGH with CR spectra from 1970s and many approximations

COSMIC-RAY SPECTRA

- Initial (proton) spectrum: abundant low-energy CRs (Ivlev et al. 2015)



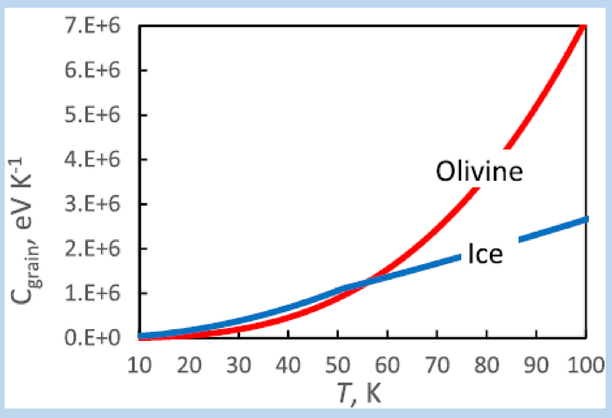
- Heavy CR elements must be considered to reproduce WGH. The abundances of ~30 CR particles were based on CR observations during Solar minimum (*George et al. 2009*; [Fe]/[H]=5×10^{-4}) or Voyager I data (*Cummings et al. 2016*; [Fe]/[H]=1×10^{-4})
- The initial spectra are attenuated by interstellar matter.



Calculated spectra of some CRs at A_V = 2 mag.

GRAIN PROPERTIES

- Grain material:
  - nuclei – olivine $MgFeSiO_4$;
  - ice – H_2O:CO:CO_2:CH_3OH.
- Grain heat capacity

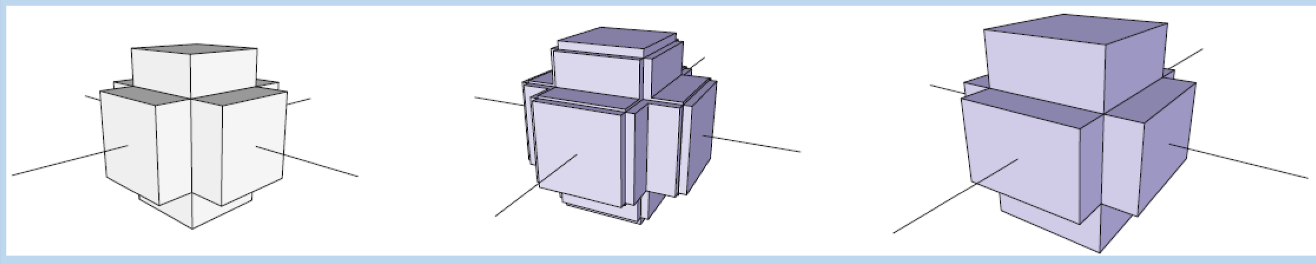


Comparison of heat capacities for olivine and ice spheres with a radius of 0.1 μm.

- Grain nuclei radius *a* considered: 0.05 μm, 0.1 μm and 0.2 μm.
- Ice layer thickness: 0.0*a*, 0.1*a*, 0.2*a*, 0.3*a* – up to 100 ice monolayers for 0.1 μm grains.

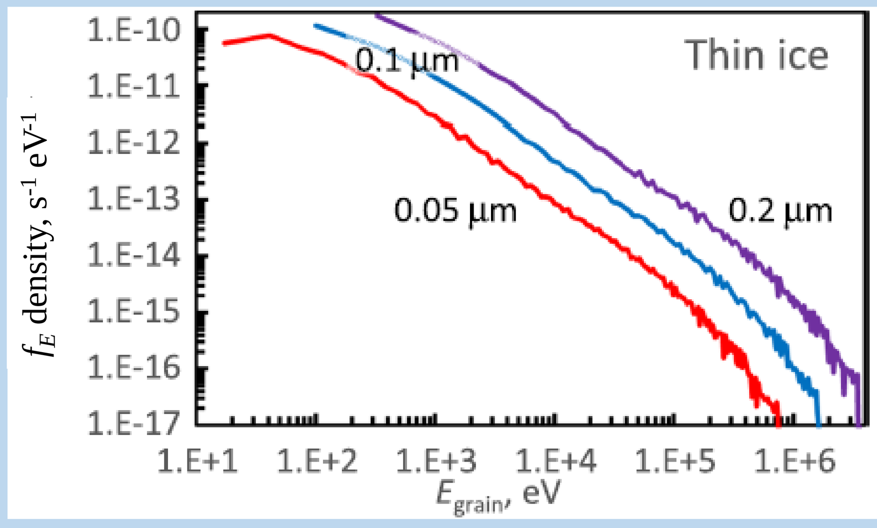
CR IMPACTS IN GRAINS

- Geometrical model for describing CR impacts:
  - limited number of CR paths through the grain;
  - surface area equal to spherical grains (determines impact frequency);
  - CR path lengths through the grain consistent with spherical grains (determines the energy lost E_{lost} by passing CR particle);
  - volume equal to spherical grains.



Bare grain. Grain with thin ice mantle. Thick ice mantle.

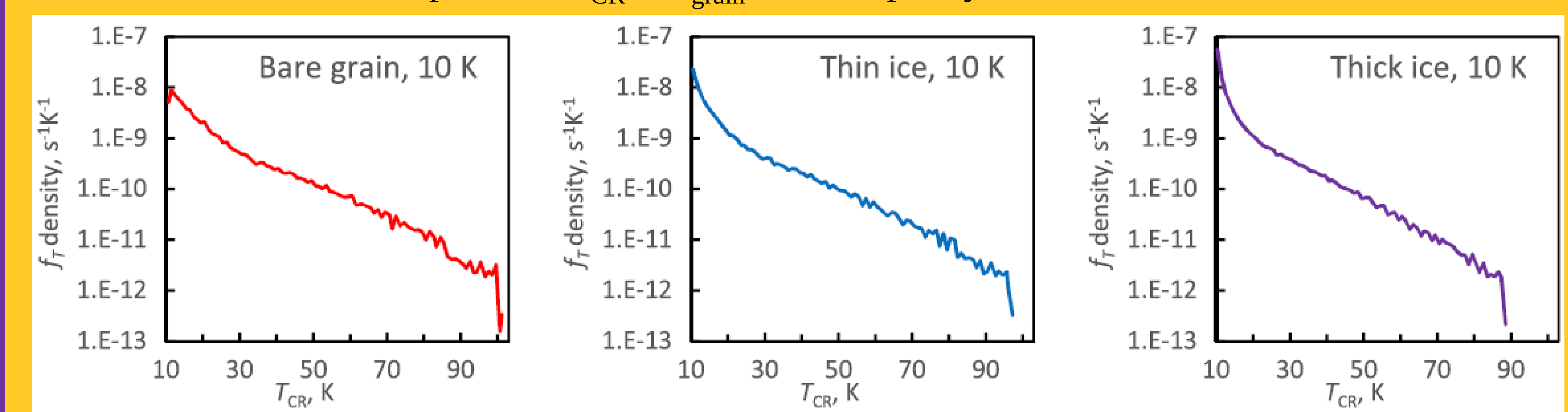
- A portion (up to ~40 %) of energy lost by CRs E_{lost} is carried away in the form of escaping fast electrons, hence $E_{lost} > E_{grain}$. The corresponding frequency is f_E.



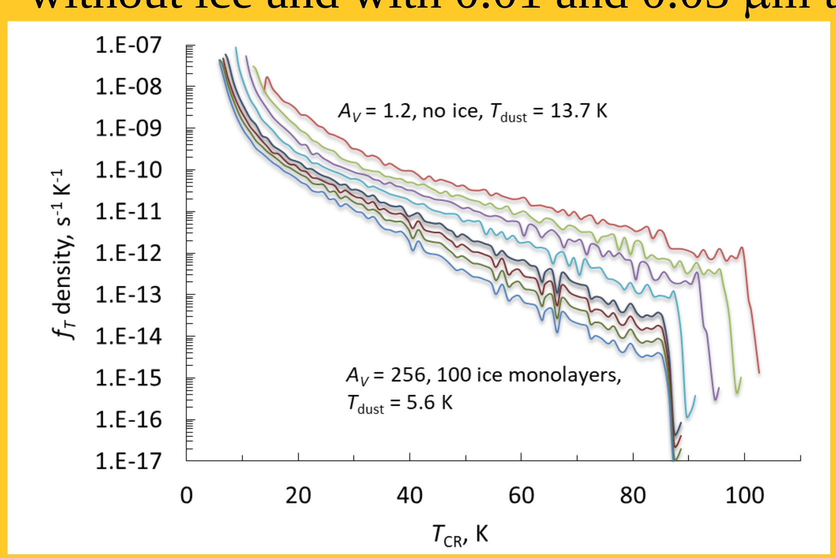
Example for CR-delivered energy spectra for grains of three sizes (*a* = 0.05; 0.1; 0.2 μm) with an ice layer of 0.1*a*.

TEMPERATURE FREQUENCY f_T OF WHOLE-GRAIN HEATING TO GRAIN TEMPERATURE T_{CR}

- Grain temperature T_{CR} = E_{grain} / heat capacity.



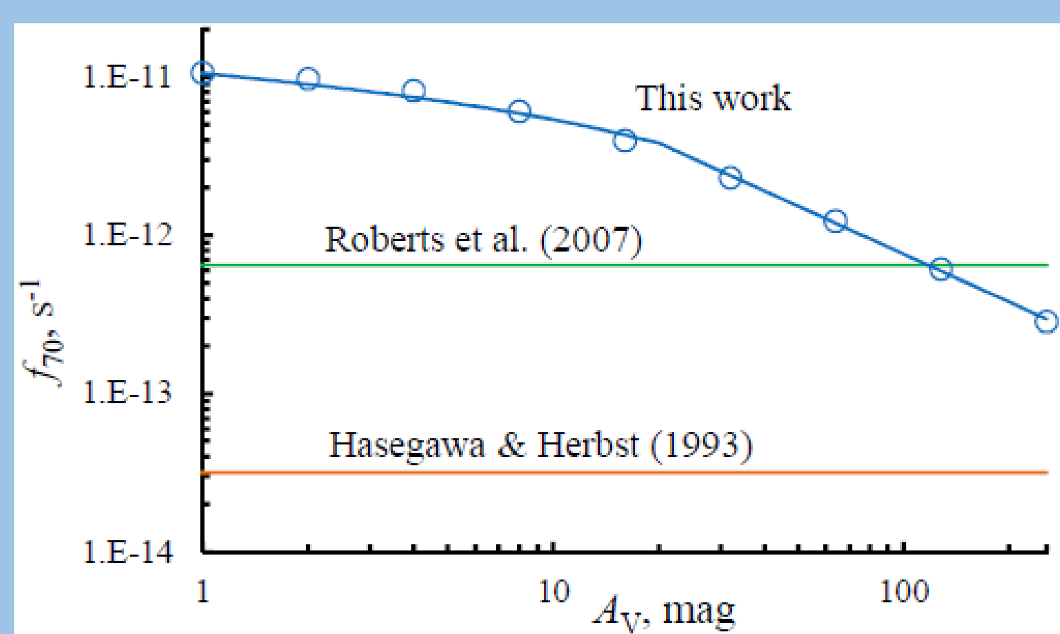
CR-induced whole-grain heating temperature spectra for 0.1 μm olivine grains at 10 K without ice and with 0.01 and 0.03 μm thick icy mantle.



← T spectra for 0.1 μm grains in cloud with varying column density (Paper III).

WGH T SPECTRA APPLICATION: UPDATED HEATING FREQUENCIES FOR INTERSTELLAR GRAINS (PAPER II)

The new, precise data require precise treatment. Shielding by interstellar gas clumps has to be considered, much like in the case of interstellar UV radiation. In addition, magnetic fields may reduce CR flux.



Calculated whole-grain heating frequency to 70 K (Appendix B of Paper II)

REFERENCES
Cummings *et al.* 2016, ApJ, **831**, 18
George *et al.* 2009, ApJ, **698**, 1666
Ivlev *et al.* 2015, ApJ, **812**, 135
Padovani & Galli 2013, ASSP, **34**, 61

Paper I: Kalvāns 2016, ApJS, **224**, 42
Paper II: Kalvāns 2018, *submitted to* MNRAS
Paper III: Kalvāns 2018, *in preparation*