

All-solid-state batteries for diverse applications

H. M. R. Wilkening

Christian Doppler Laboratory for Lithium Batteries
The Graz University of Technology



(EVs (not) included)

TU
Graz ■

industrial partners

research topics

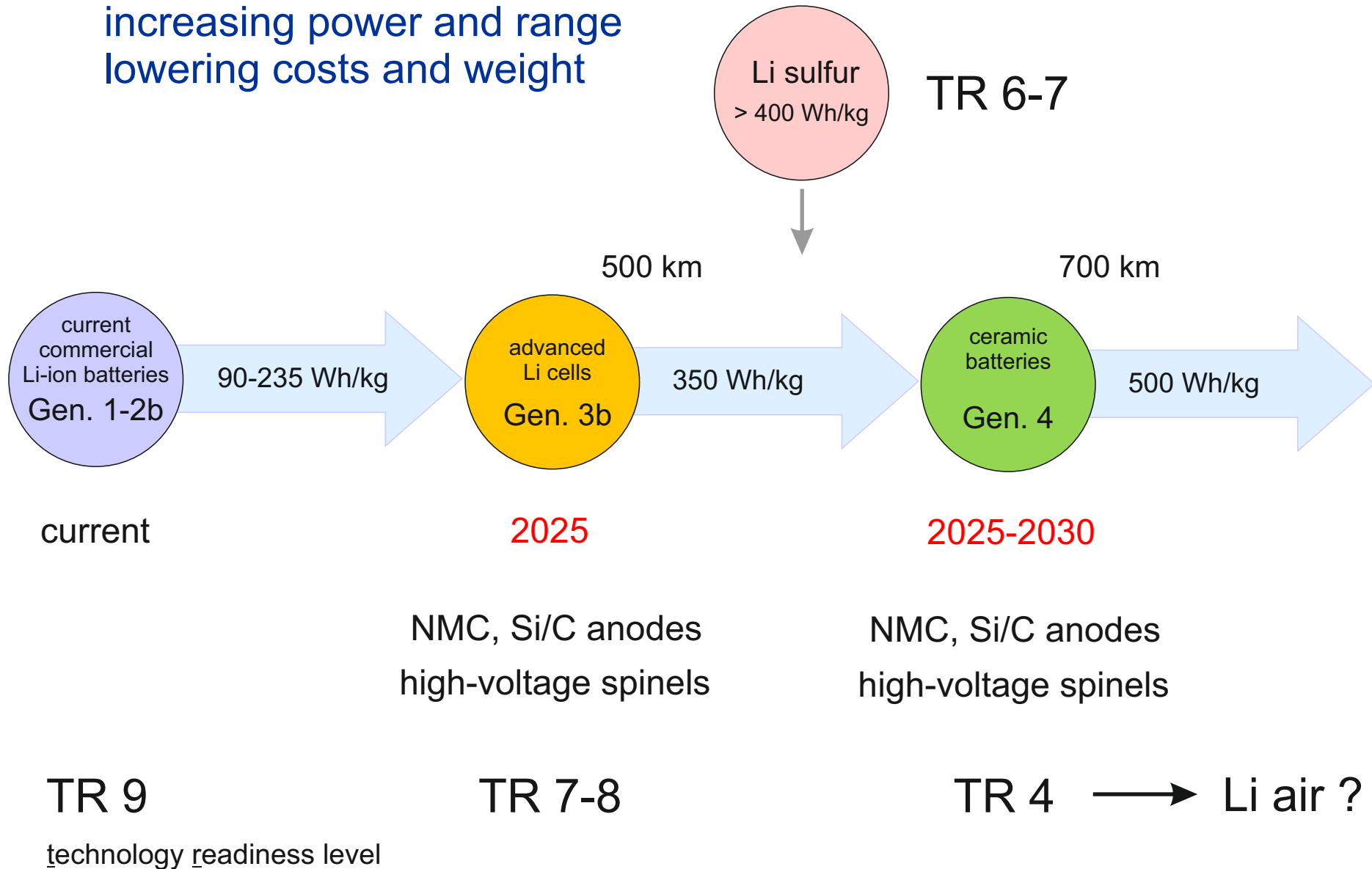
Christian-Doppler-Laboratory
for Lithium-Batteries



- ageing effects (Tesla's Panasonic cells), ...
- μ -batteries using single crystalline silicon, ...
- all-solid-state lithium batteries, ...

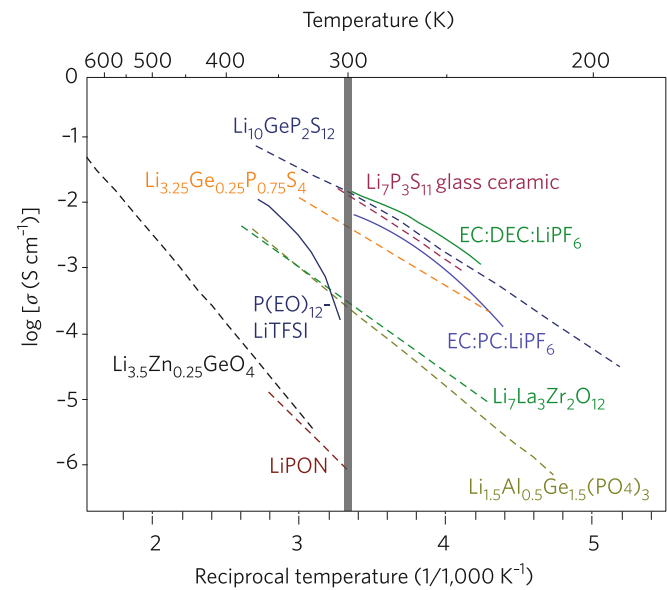
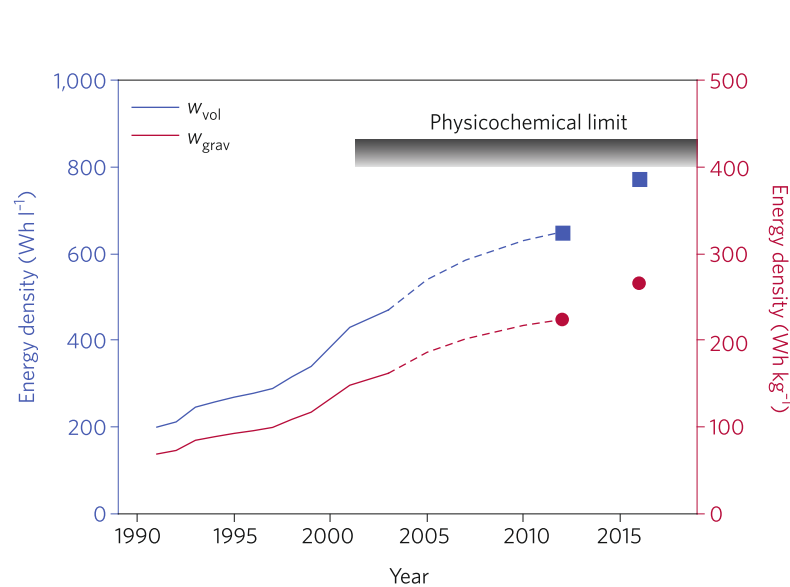
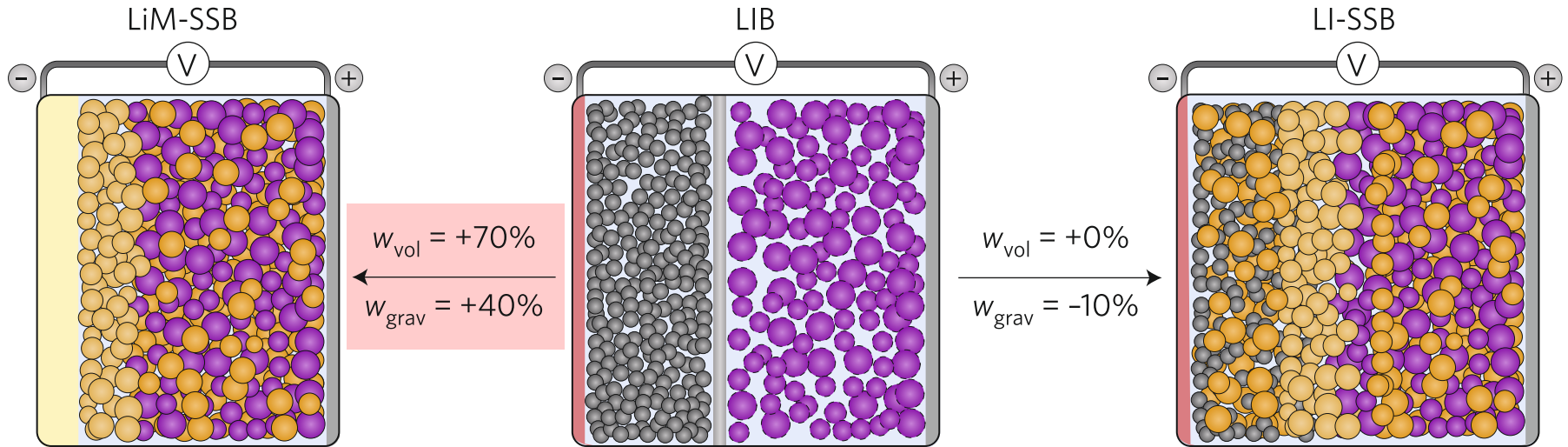
the new battery generations

increasing power and range
lowering costs and weight



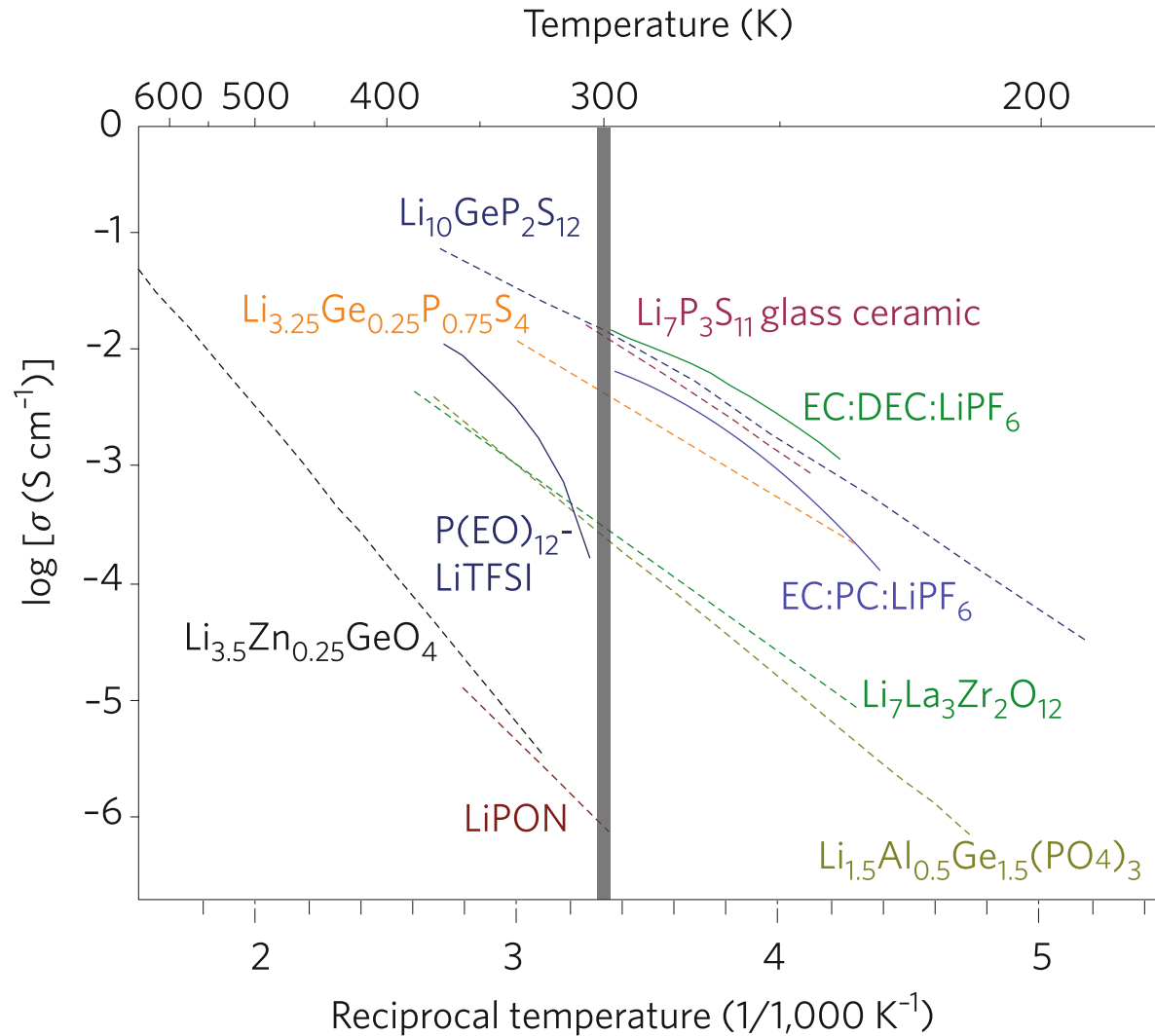
all-solid-state systems

Zeier/Janek, Nature Energy, 2016



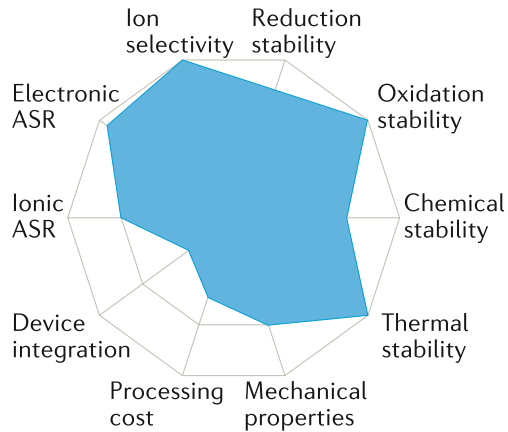
■ solid electrolytes

Zeier/Janek, Nature Energy, 2016

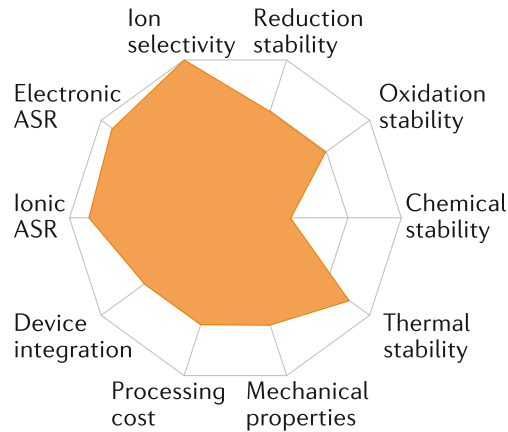


■ ... from oxides to hydrides? (and back again)

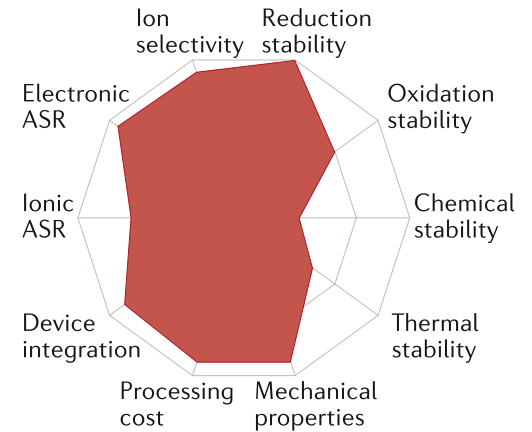
a Oxide



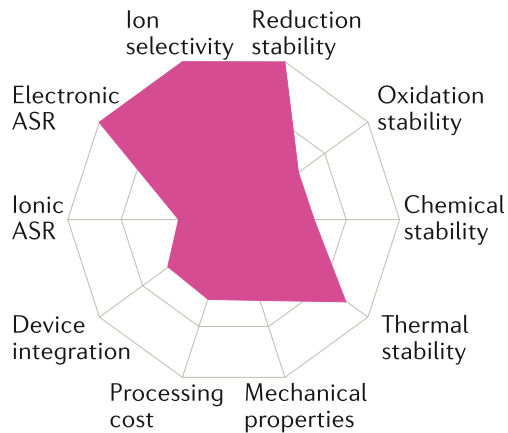
b Sulfide



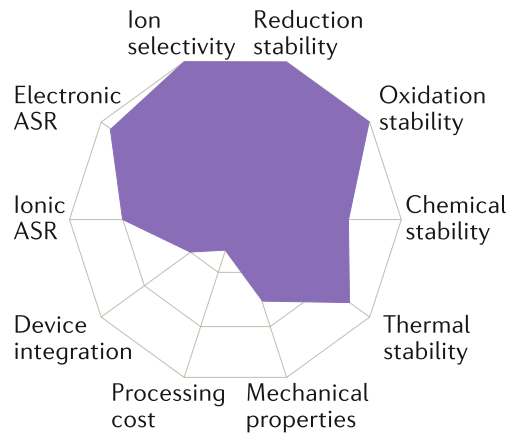
c Hydride



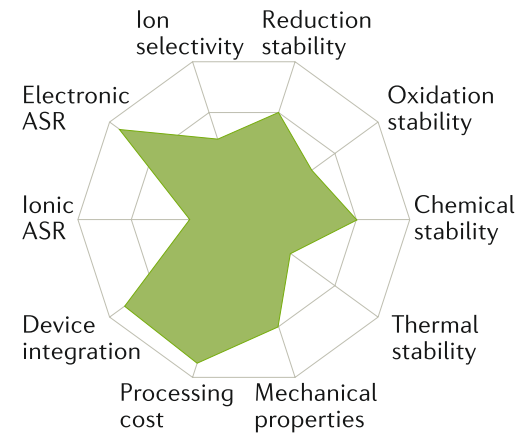
d Halide



e Thin film



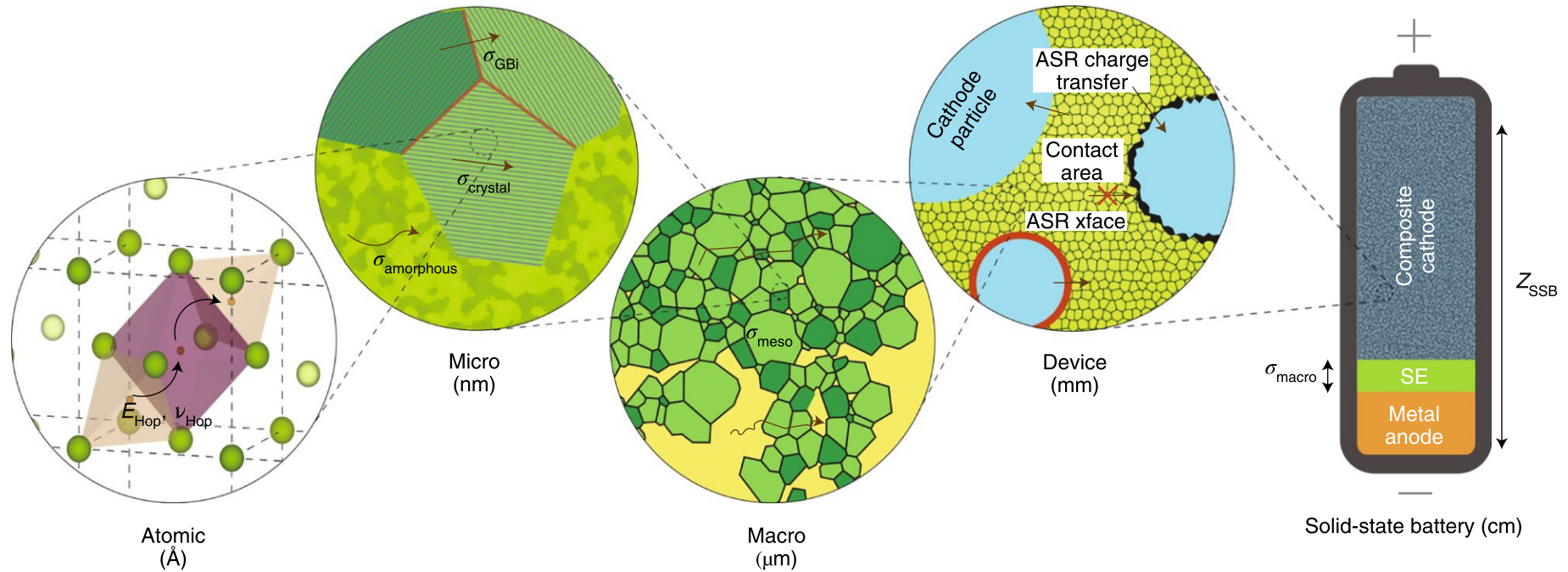
f Polymer



Manthiram, Nature Reviews, Materials, 2017

ion transport in solids

... solid state ionics



TU Graz

TU Graz

Nuclear magnetic resonance

Impedance spectroscopy

Molecular dynamics

Continuum modelling

Diffraction, pair distribution function analysis

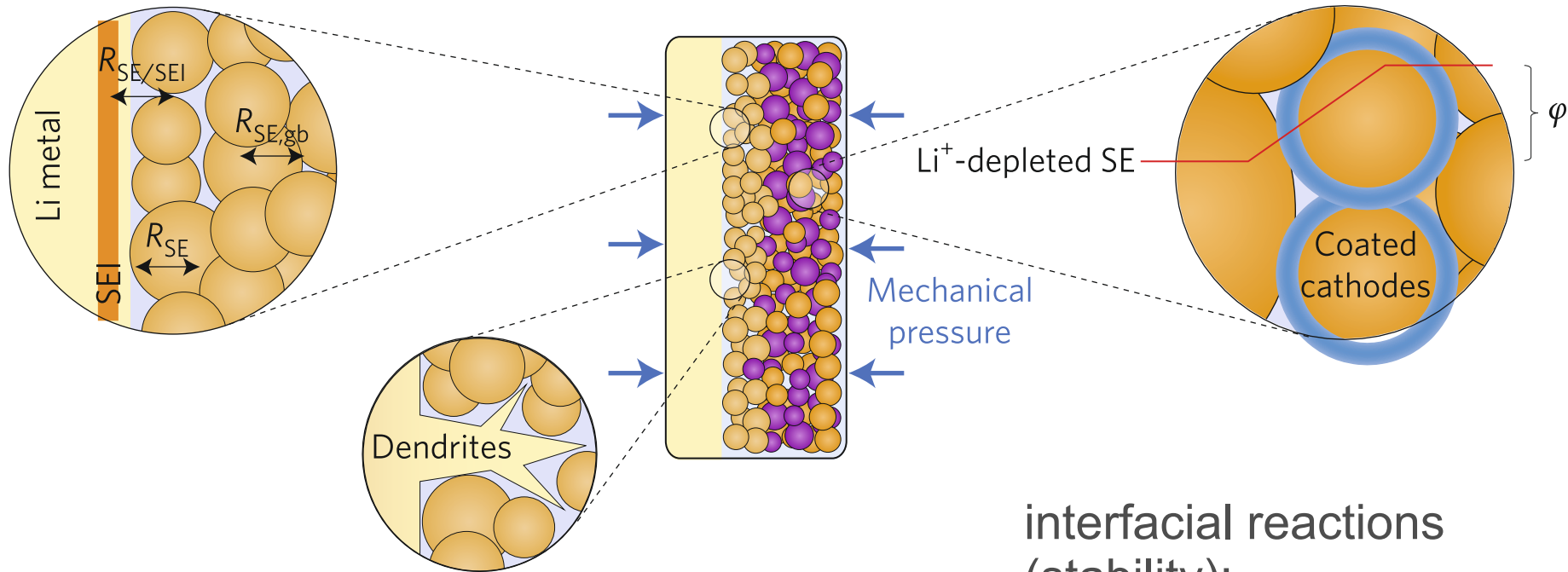
Electron microscopy

Vibrational spectroscopy

Famprikis et al., Nature Mater., 2019

■ solid electrolytes

... hurdles, partly overcome, others need to be surmounted

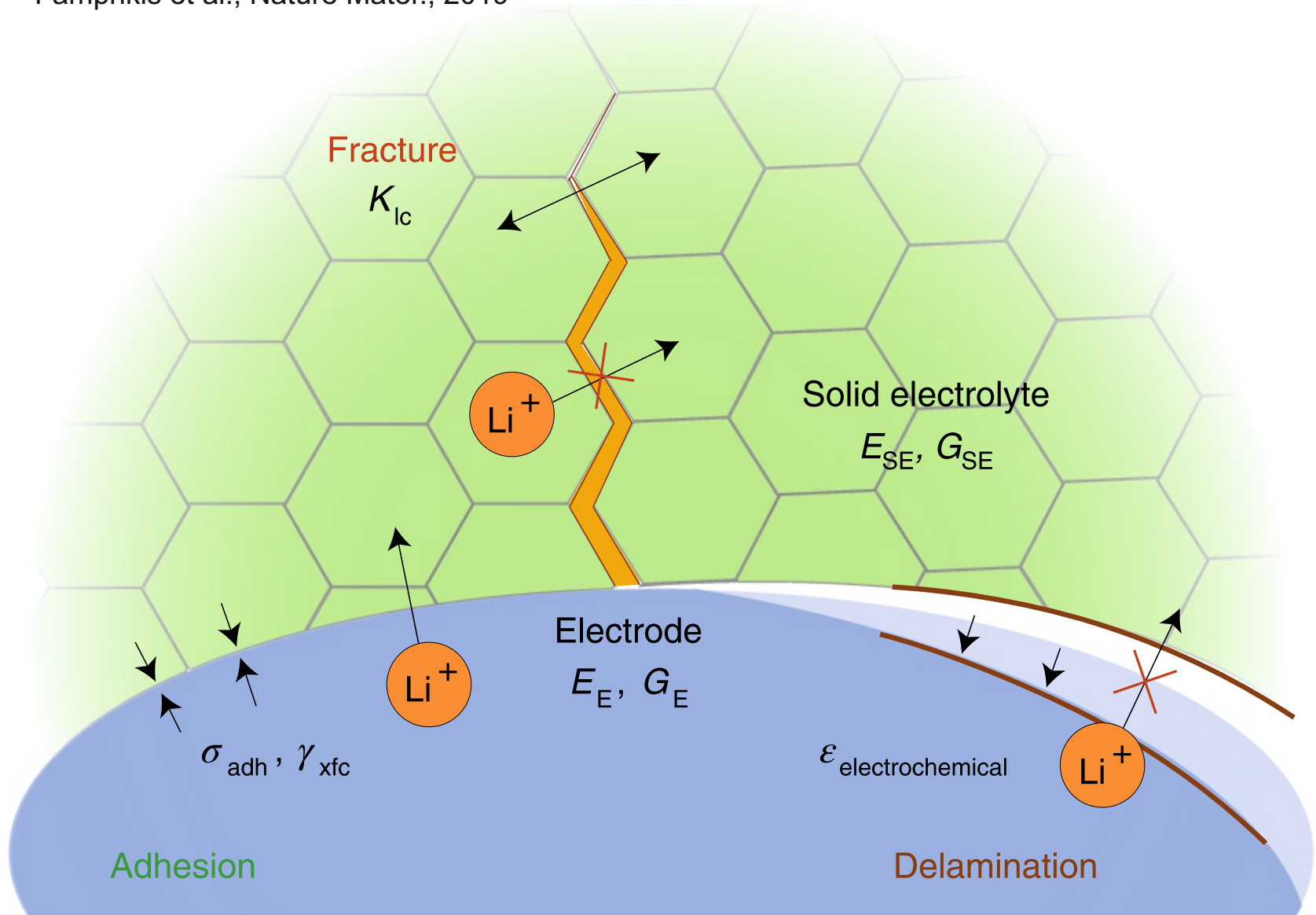


interfacial reactions
(stability):

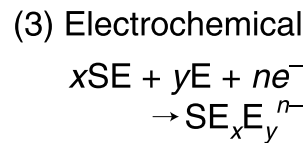
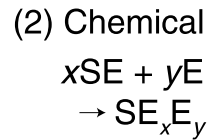
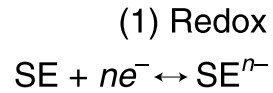
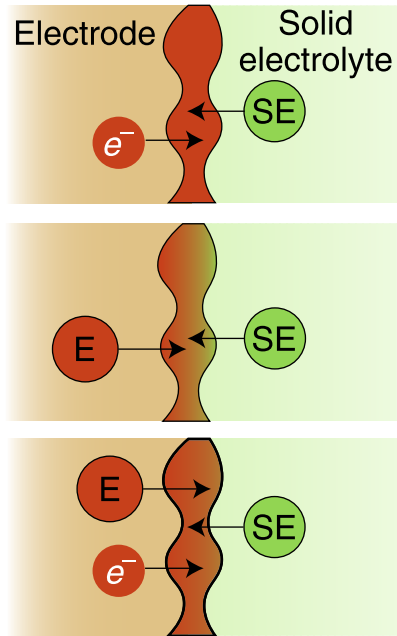
Li dendrites

stability and degradation www.lithium.tugraz.at

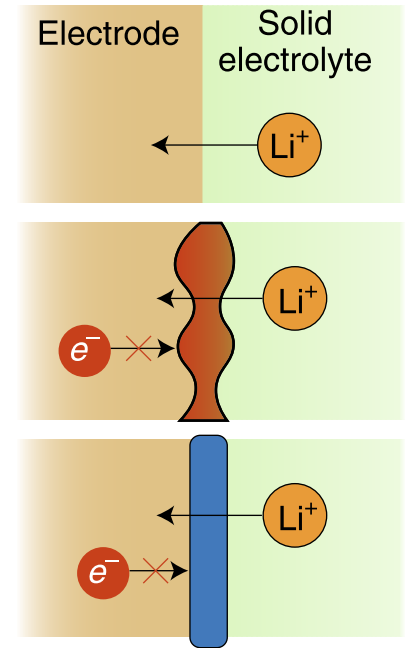
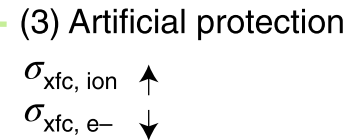
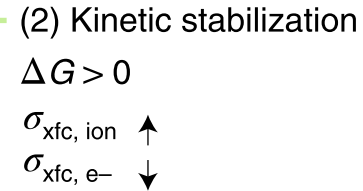
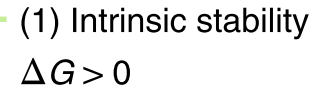
Famprakis et al., Nature Mater., 2019



Reaction possibilities

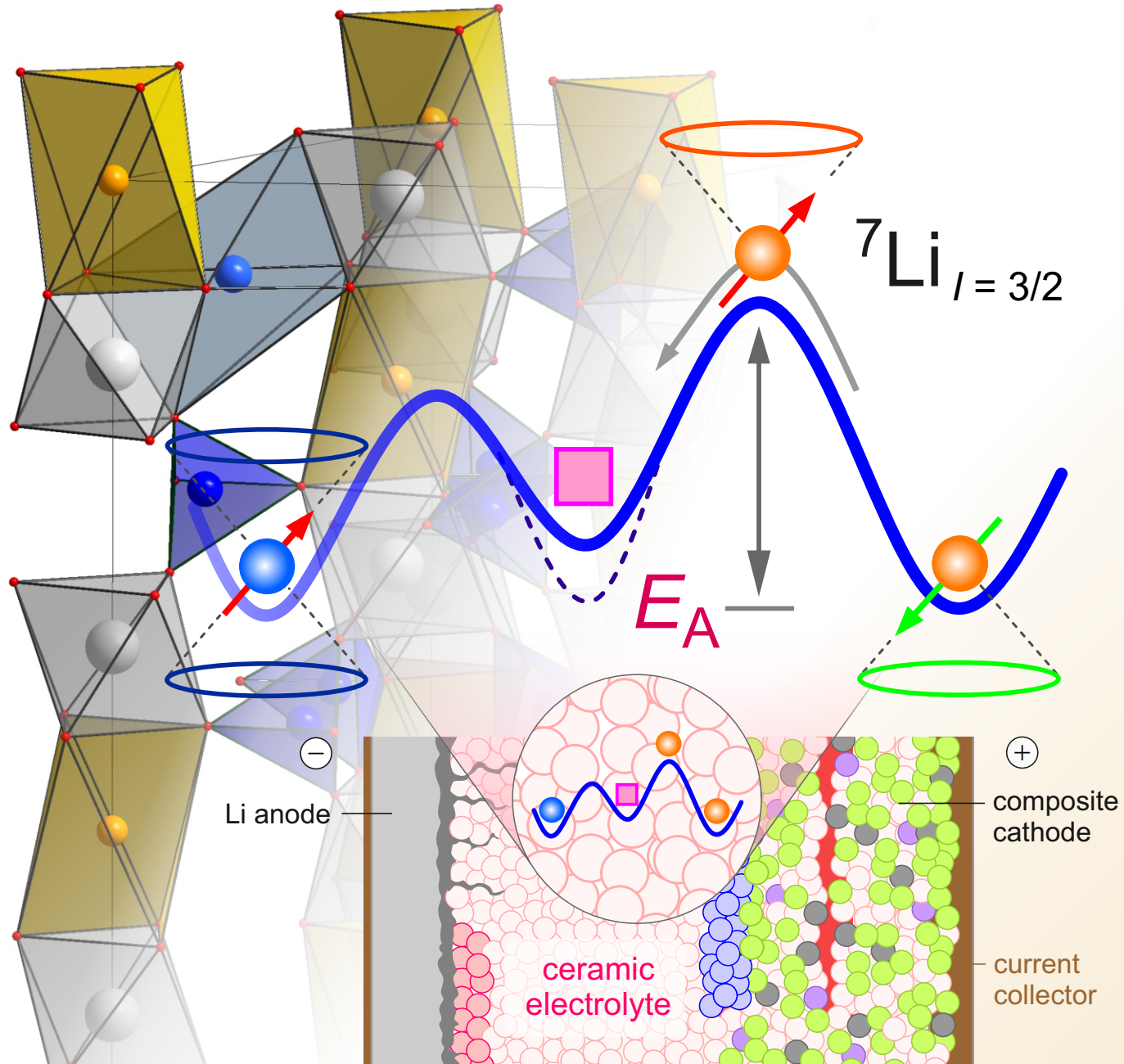


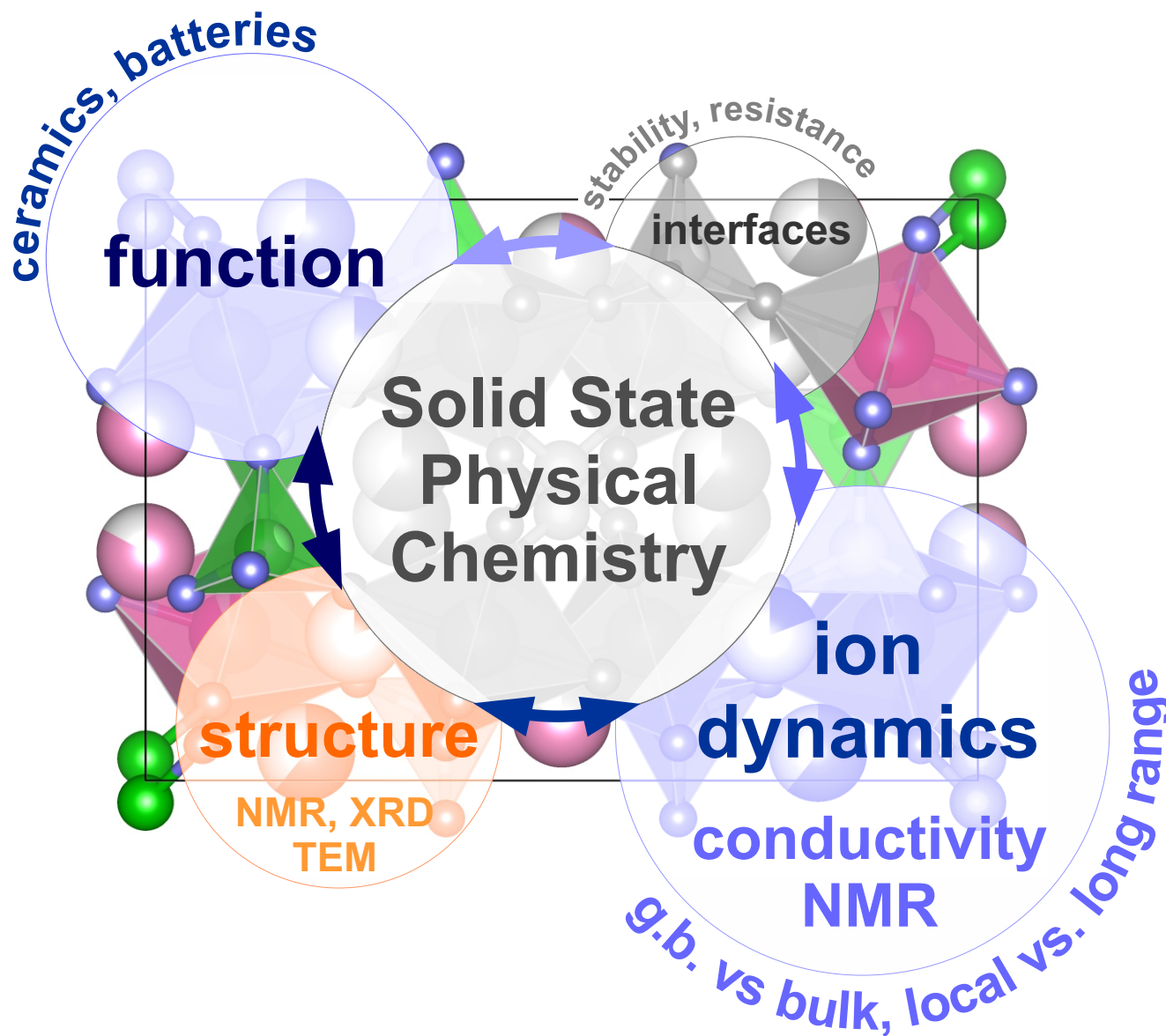
Functional scenarios



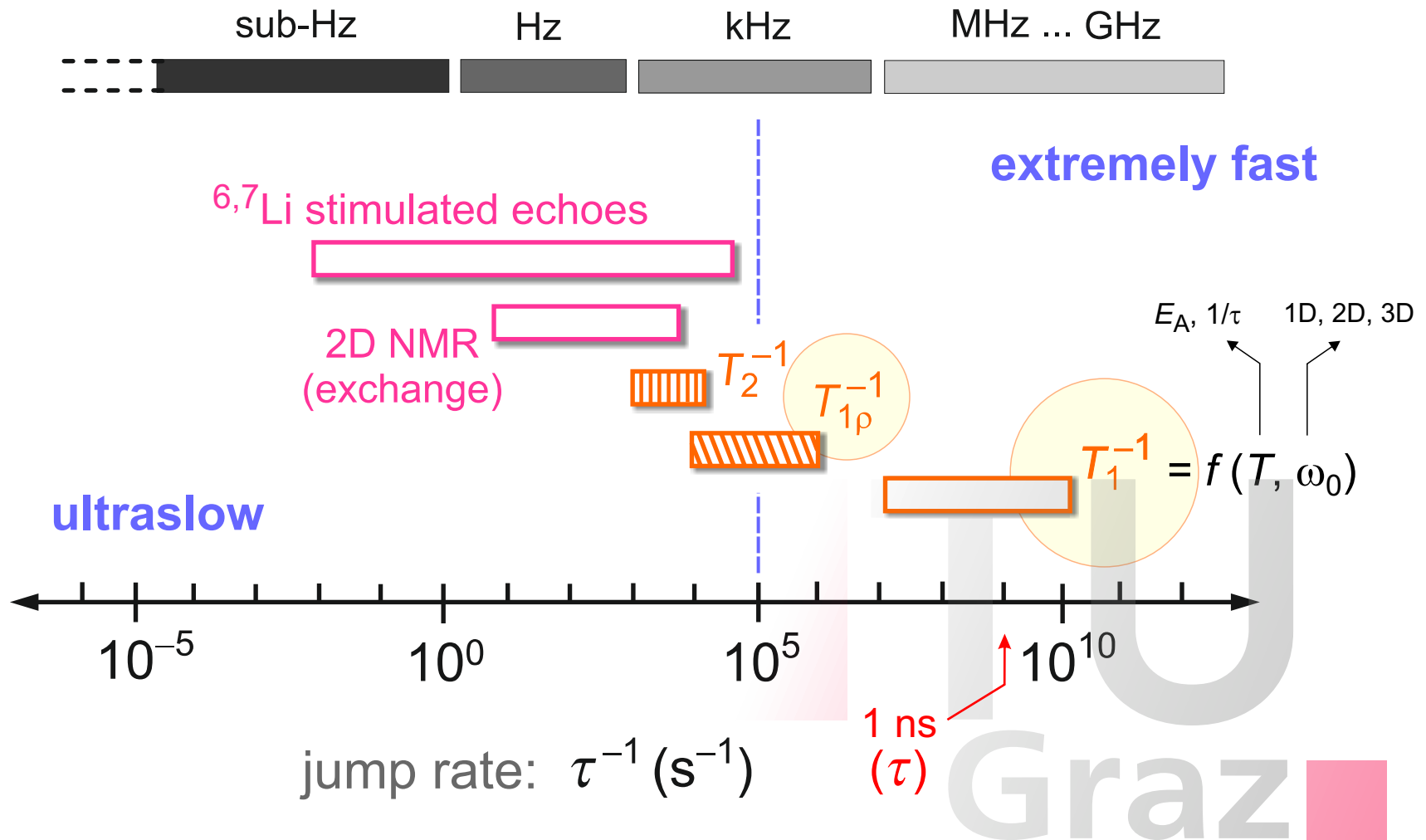
... *non-equilibrium system*

ageing, evolution of interfacial layers with time, ...





hopping processes





- **LATP: bulk vs. g.b.** PCCP,
J. Mater. Chem.

lithium aluminum phosphates
Li(7) spin-lock NMR
low T broadband conductivity spectr.

- **garnets: LLZO-based** Chem. Mater.
Inorg. Chem.

LLZMO, Mo on Zr sites
LLZTO, Ta on Zr sites, single crystal
Al-/Ga-bearing LLZO

- **thiophosphates
argyrodites** J. Phys. Chem. Lett.
ChemPhysChem
J. Phys. Chem. C

Li-7-P-11 phase, $\text{Li}_7\text{P}_3\text{S}_{11}$
 γ - and β - Li_3PS_4

ion dynamics

■ Thank you!

www.ictm.tugraz.at



... Isabel, Caroline, Marlena, Bernhard G., Marina, Maria, Roman, Hannes, Ina, ...

■ Thank you!

www.ictm.tugraz.at

bmwfw

Bundesministerium für
Wissenschaft, Forschung und Wirtschaft

Christian Doppler
Forschungsgesellschaft

