

# PCM Screening: High Temperature Phase Change Materials

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<sup>2</sup> - GTT-Technologies

# PCM-Screening:

## Evaluation of Eutectic Mixtures for Use as PCM: Thermodynamic Modelling and Experimental Methods

Gefördert durch:



Bundesministerium  
für Wirtschaft  
und Energie

High Temperature PCMs



Low Temperature PCMs

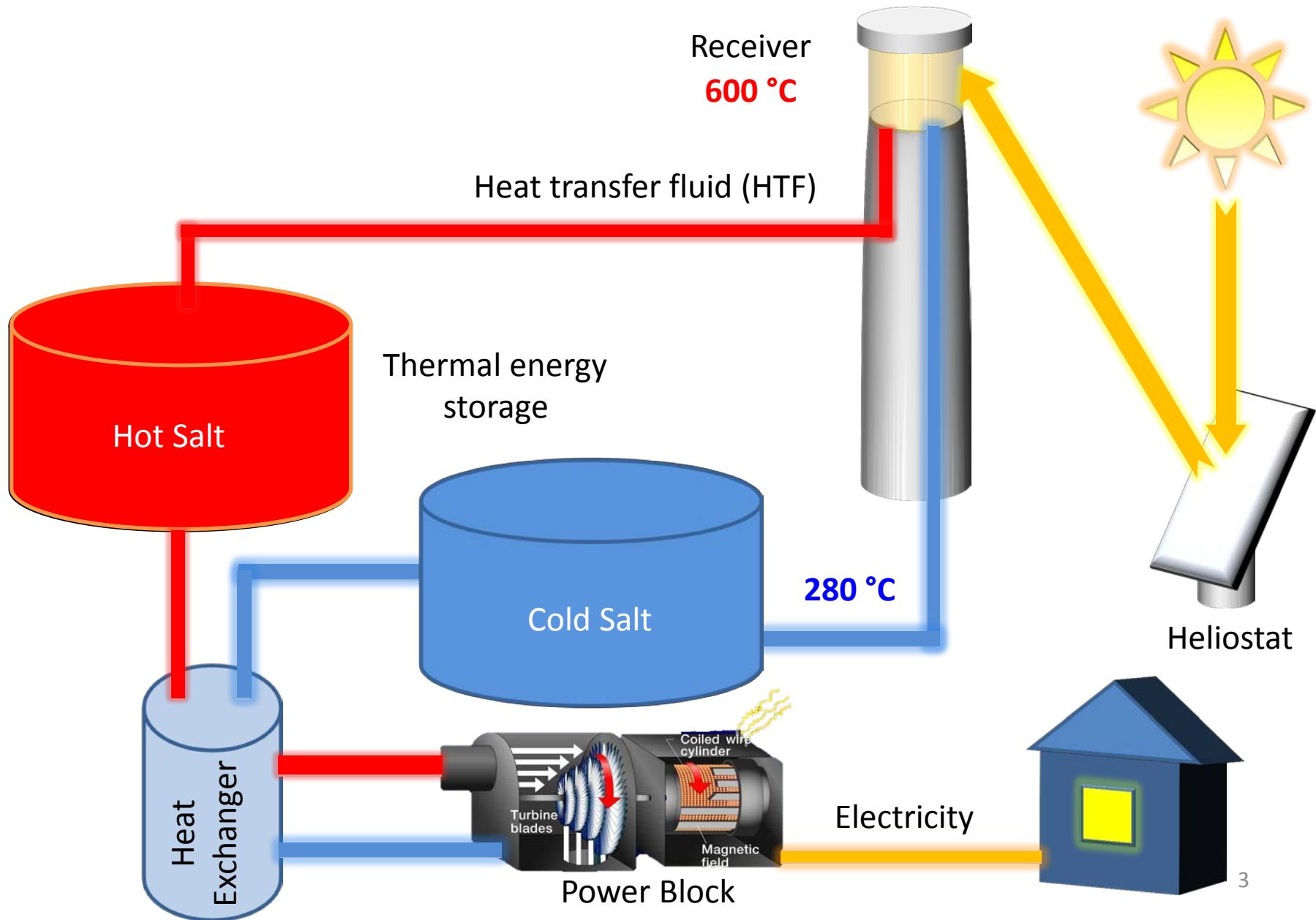


Modelling

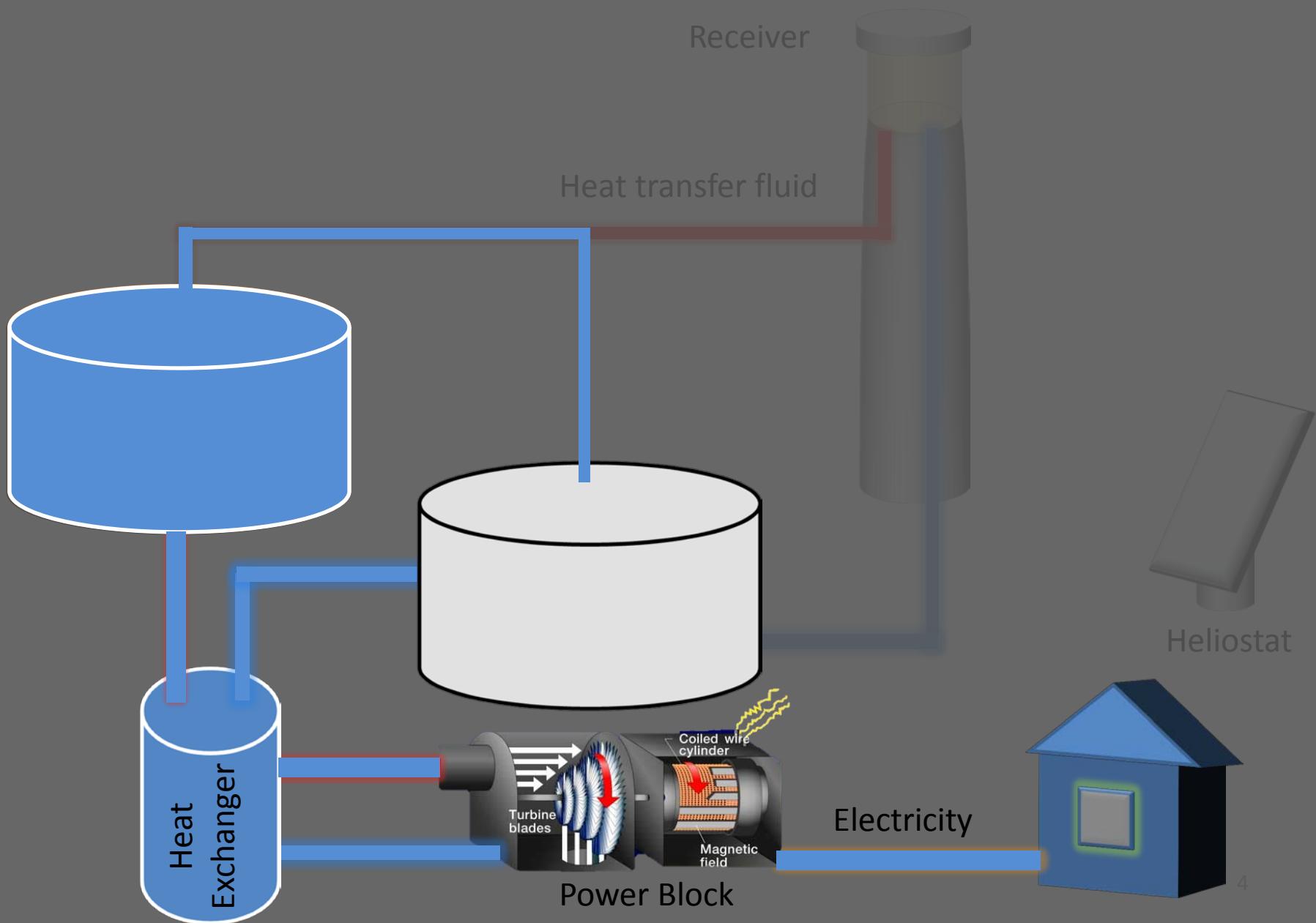
GTT - TECHNOLOGIES



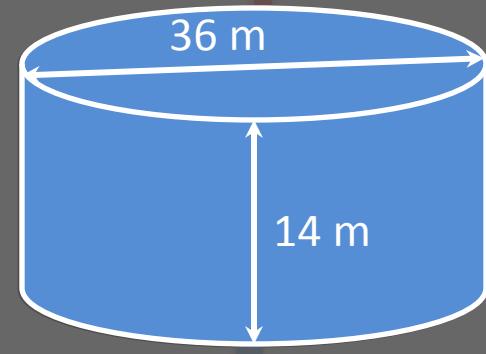
# Scheme of Solar Power Plant



# Scheme of Solar Power Plant



# Thermal Energy Storage



28 500 tons  
40%KNO<sub>3</sub>-60%NaNO<sub>3</sub>

Heat Exchanger

Power Block

Receiver

Project Name: Extresol-3 (EX-3)

Country: Spain

Start Year: 2012

Solar-Field Inlet Temp: 293°C

Solar-Field Outlet Temp: 393°C

Solar-Field Temp

Difference: 100°C

Storage Type: 2-tank indirect

Storage Capacity: 7.5 hour(s)

Thermal Storage

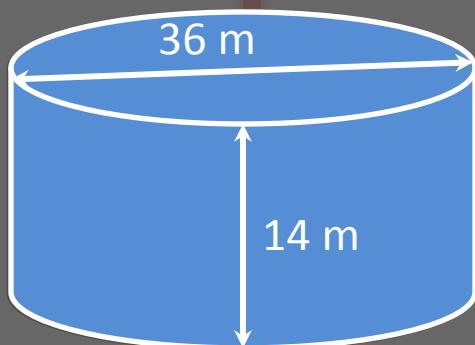
Description:

28 500 tons of molten salt. 60% sodium nitrate, 40% potassium nitrate. 1,010 MWh. Tanks are 14 m high and 36 m in diameter.

<http://www.nrel.gov/csp/solarpaces>

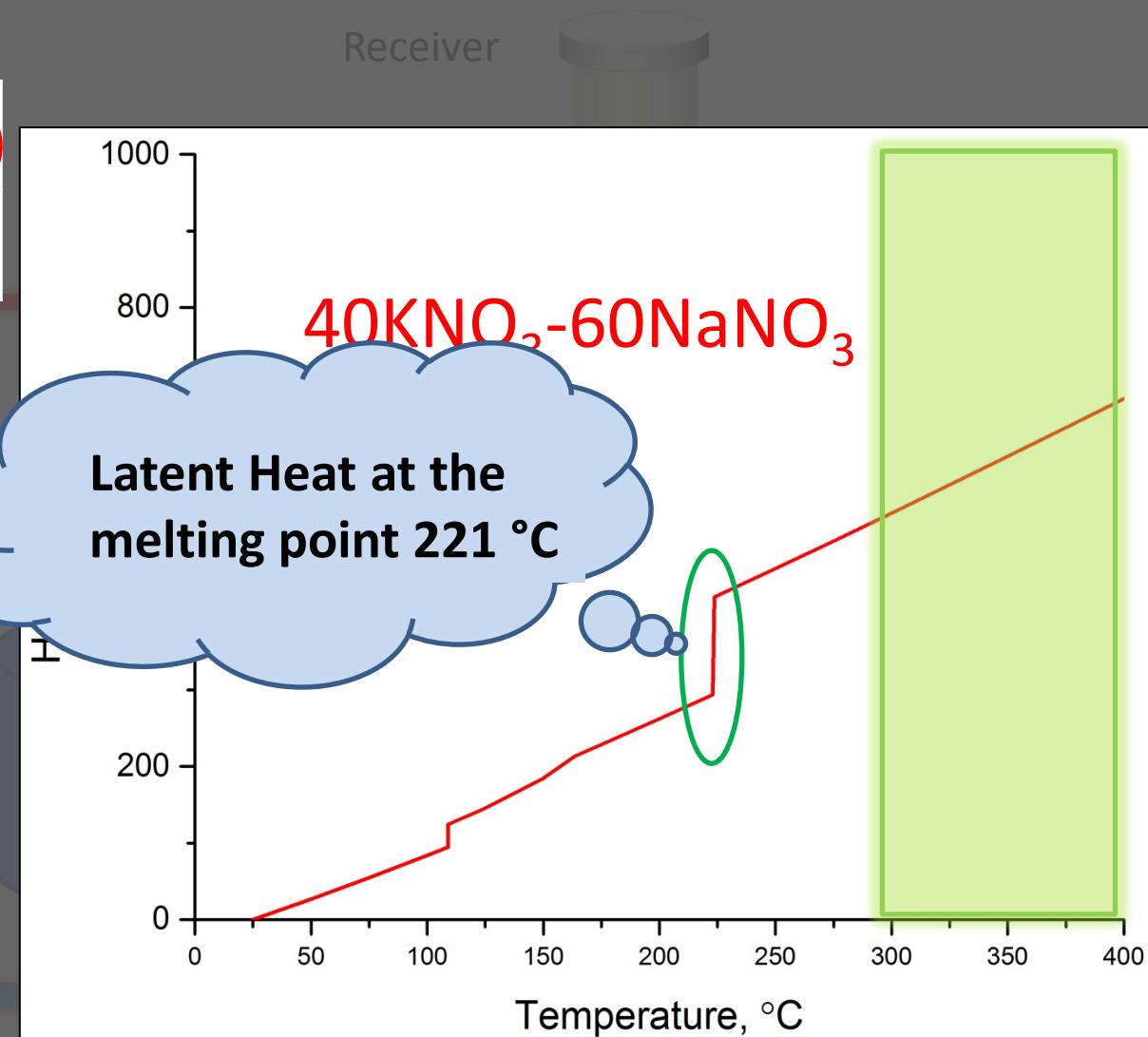
# Enthalpy Increment

Solar-Field Inlet Temp:	293°C
Solar-Field Outlet Temp.	393°C
Solar-Field Temp Difference:	100°C



28 500 tons  
40%KNO<sub>3</sub>-60%NaNO<sub>3</sub>

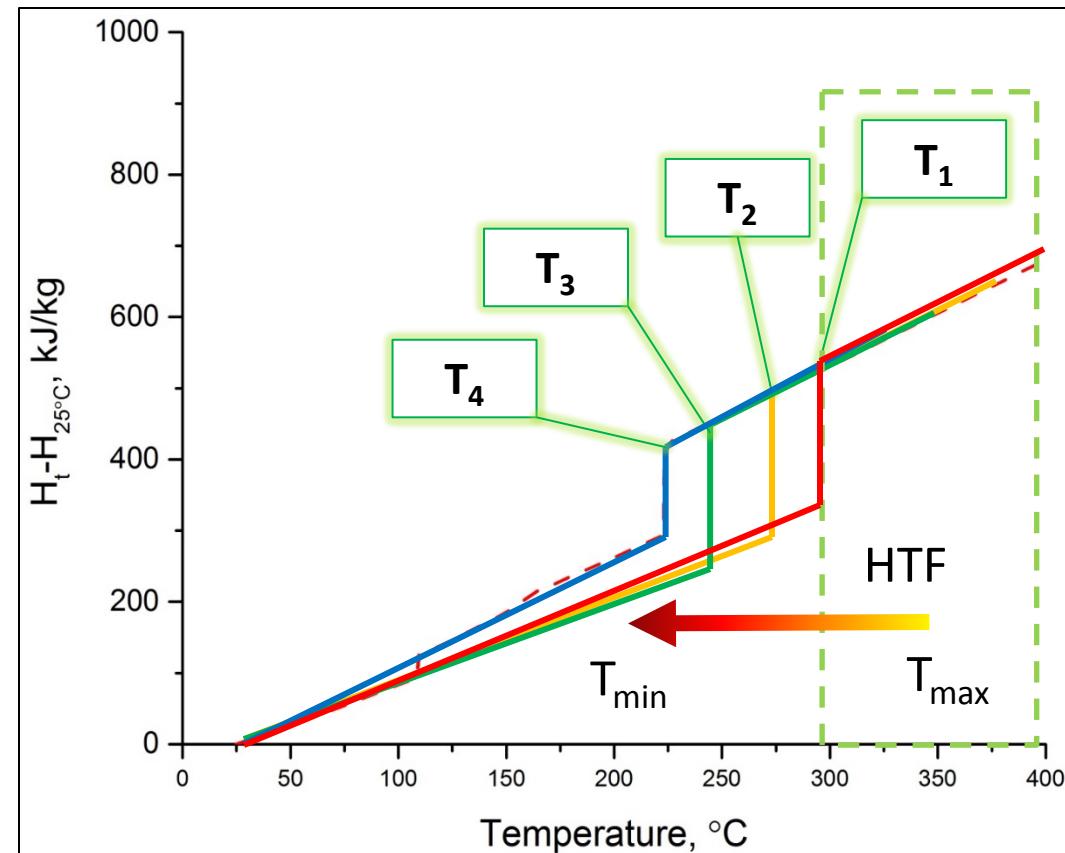
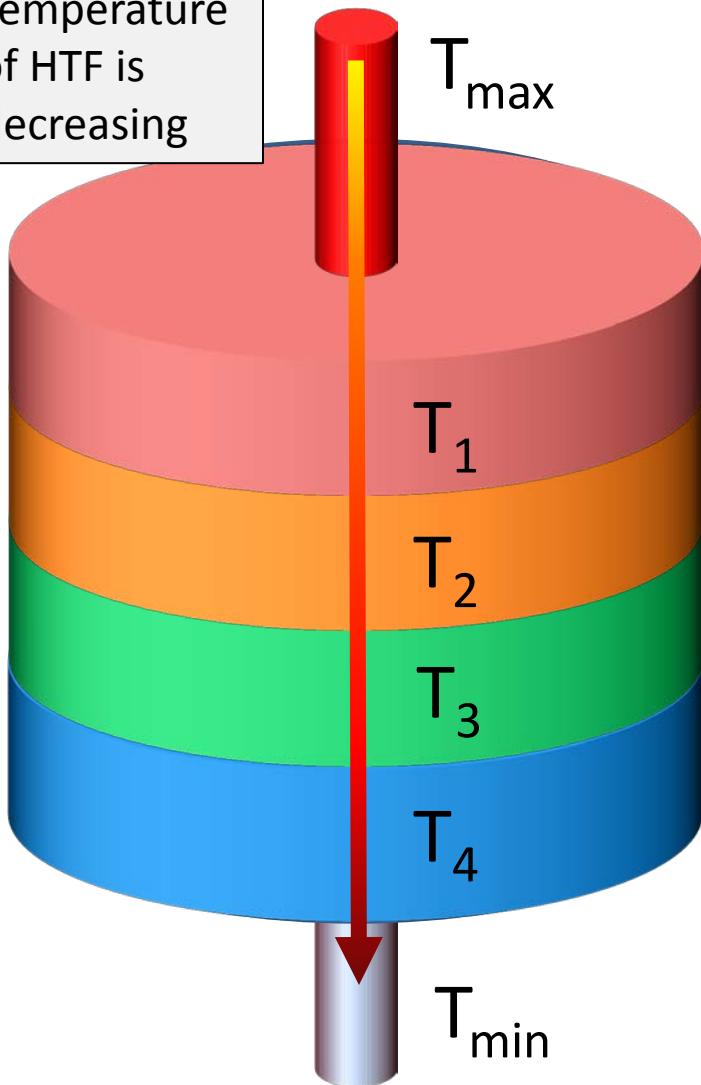
Heat Exchanger



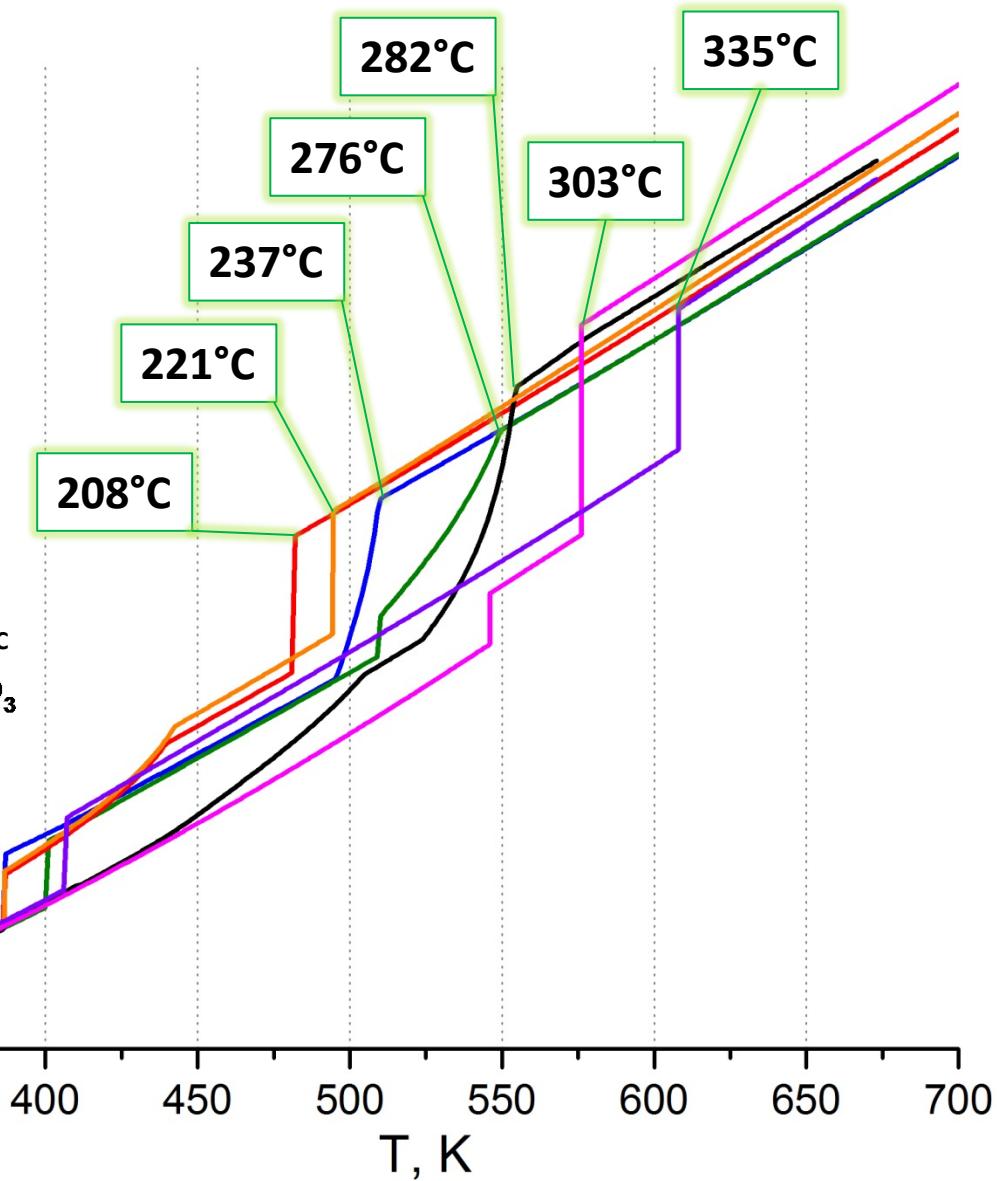
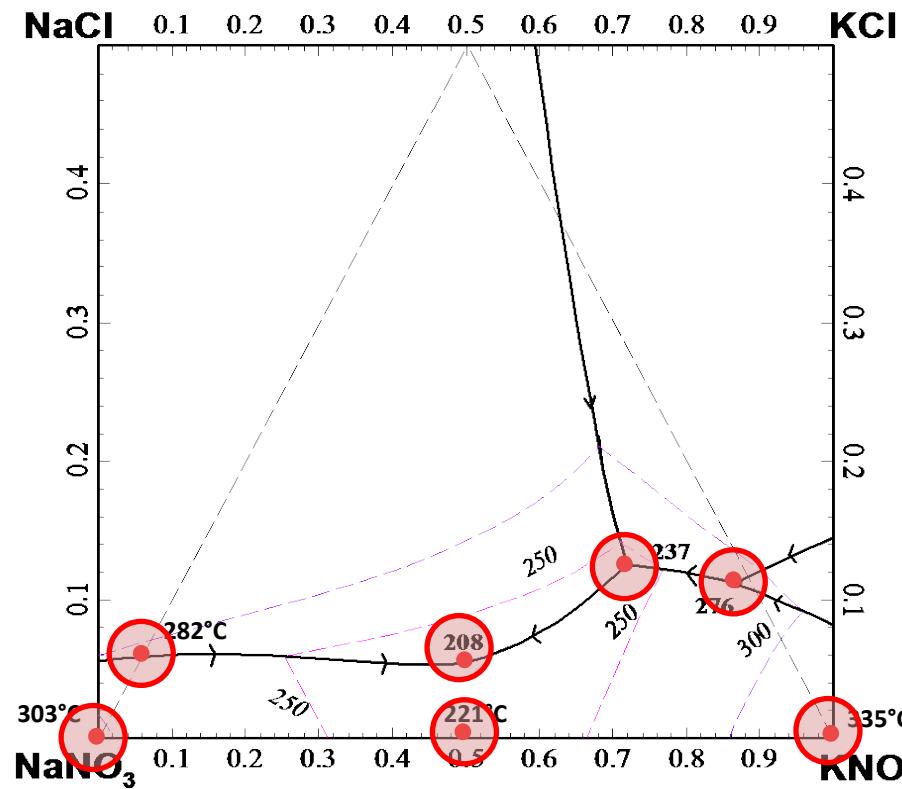
Power Block

# Cascaded Latent Heat Storage

Temperature  
of HTF is  
decreasing

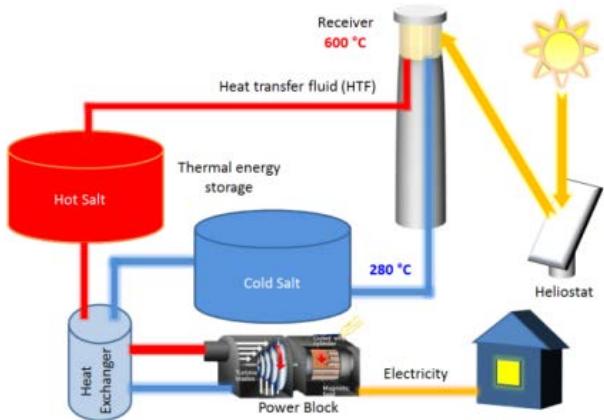


# Cascaded Latent Heat Storage



# PCM-Screening

Scheme of Solar Power Plant



Multicomponent  
Systems

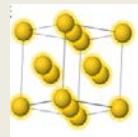
Reciprocal Systems

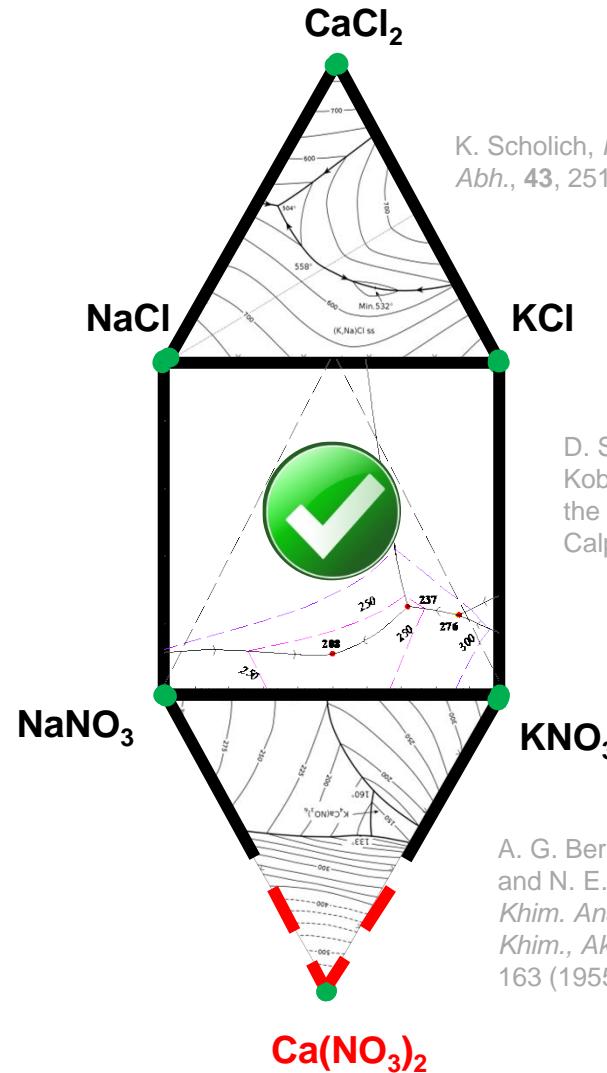
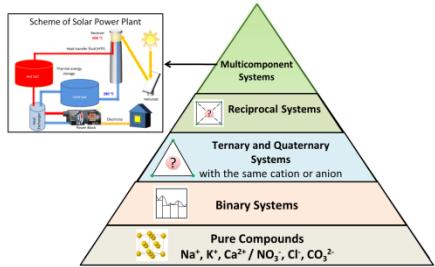
Ternary and Quaternary  
Systems

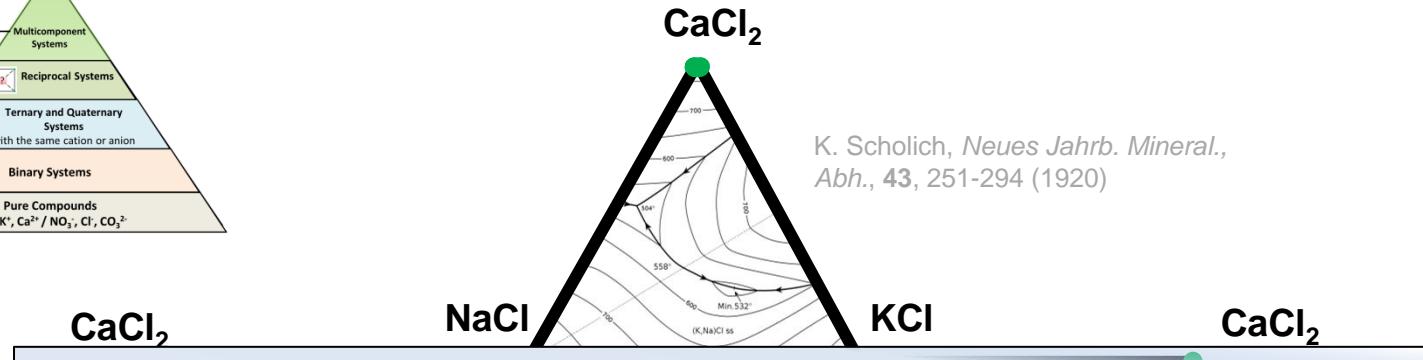
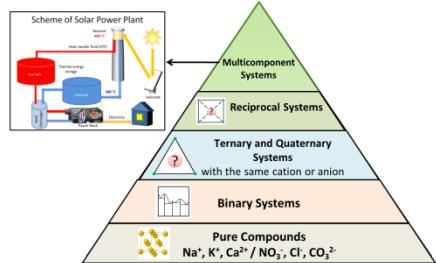
with the same cation or anion

Binary Systems

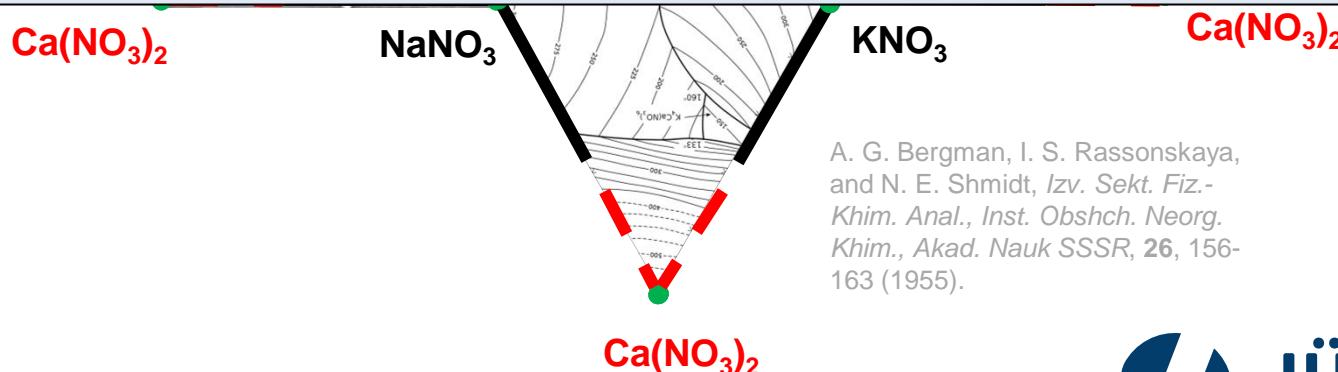
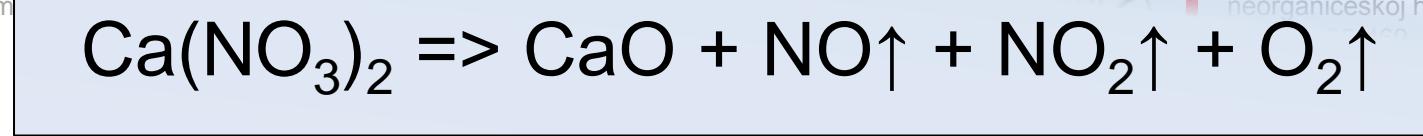
Pure Compounds



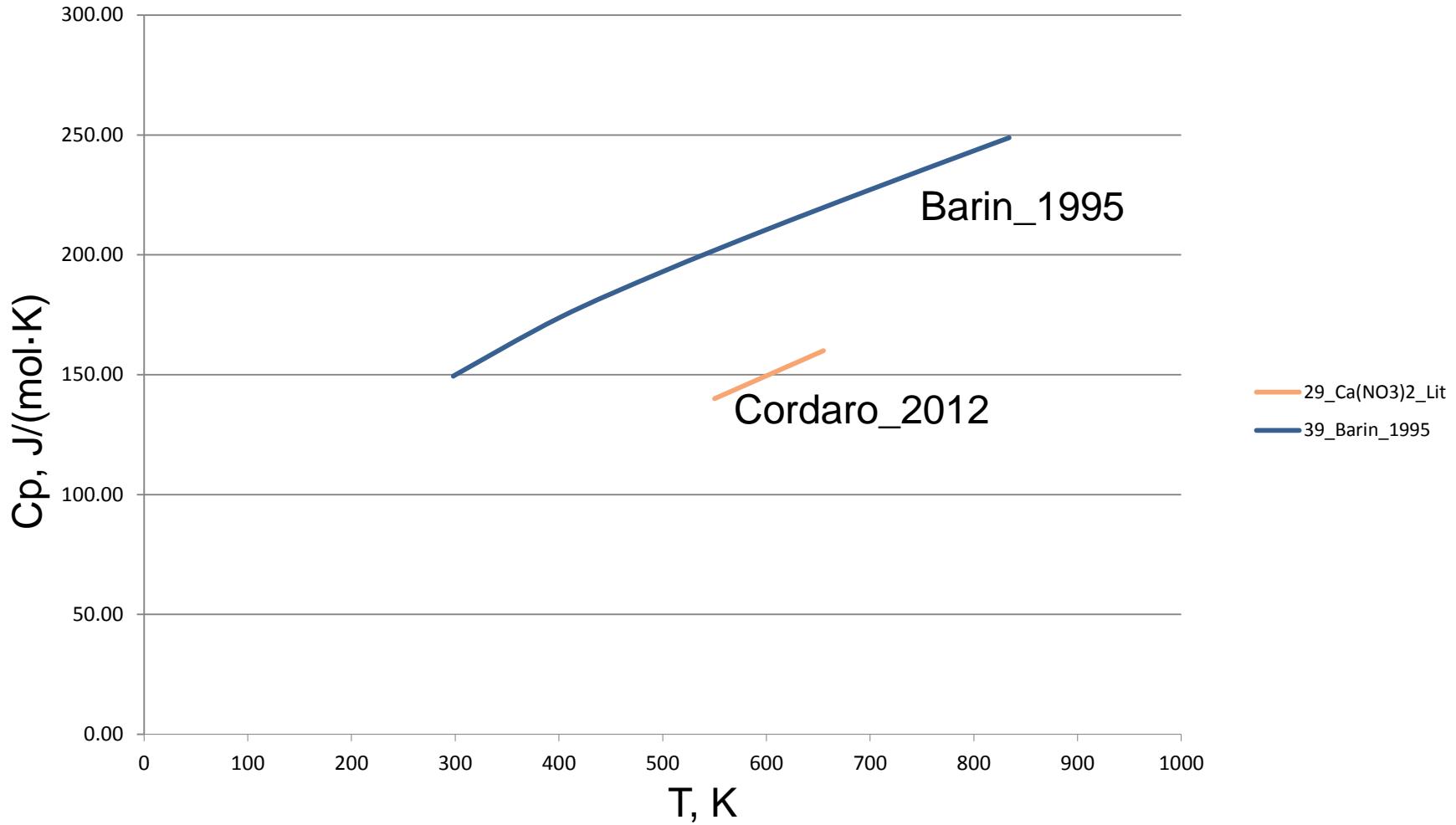




A.I. Sechnoi, Y.G. Litvinov, I.I.  
 Il'yasov, A.S. Trunin, I.K.  
 Garkushin, Žurnal  
 neorganičeskoj himii  
 (1988) 465-469.



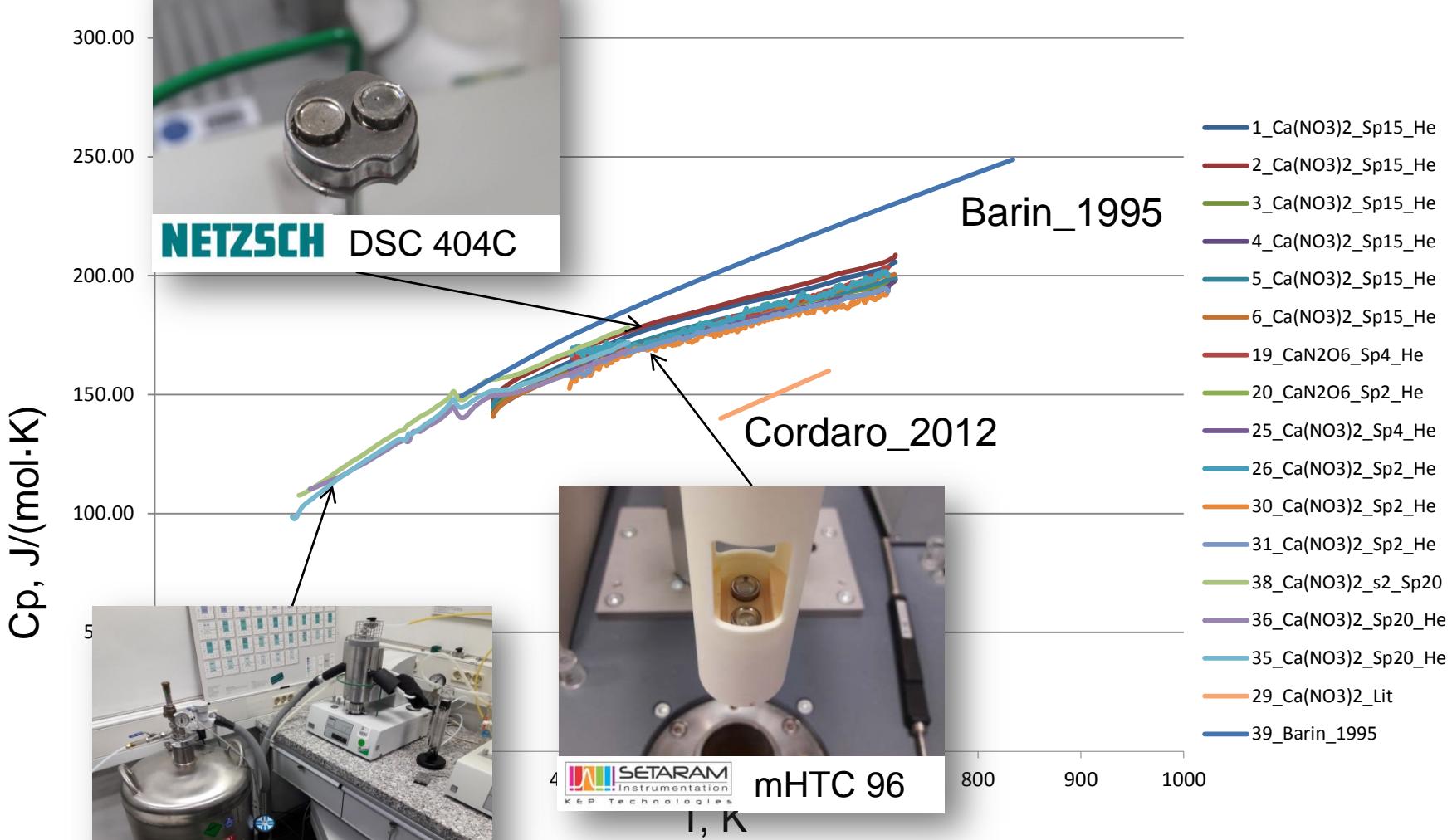
# Heat capacity of $\text{Ca}(\text{NO}_3)_2$



J.G. Cordaro, A.M. Kruizenga, R. Altmaier, M. Sampson, A. Nissen, THERMODYNAMIC PROPERTIES OF MOLTEN NITRATE SALTS  
<http://energy.sandia.gov/wp-content/gallery/uploads/Thermodynamic-Poroperties-of-Molten-Nitrate-Salts-Cordaro.pdf>, (2012).

I. Barin, Thermochemical Data of Pure Substances, 3rd ed., VCH Verlag GmbH, Weinheim, Germany, 1995.

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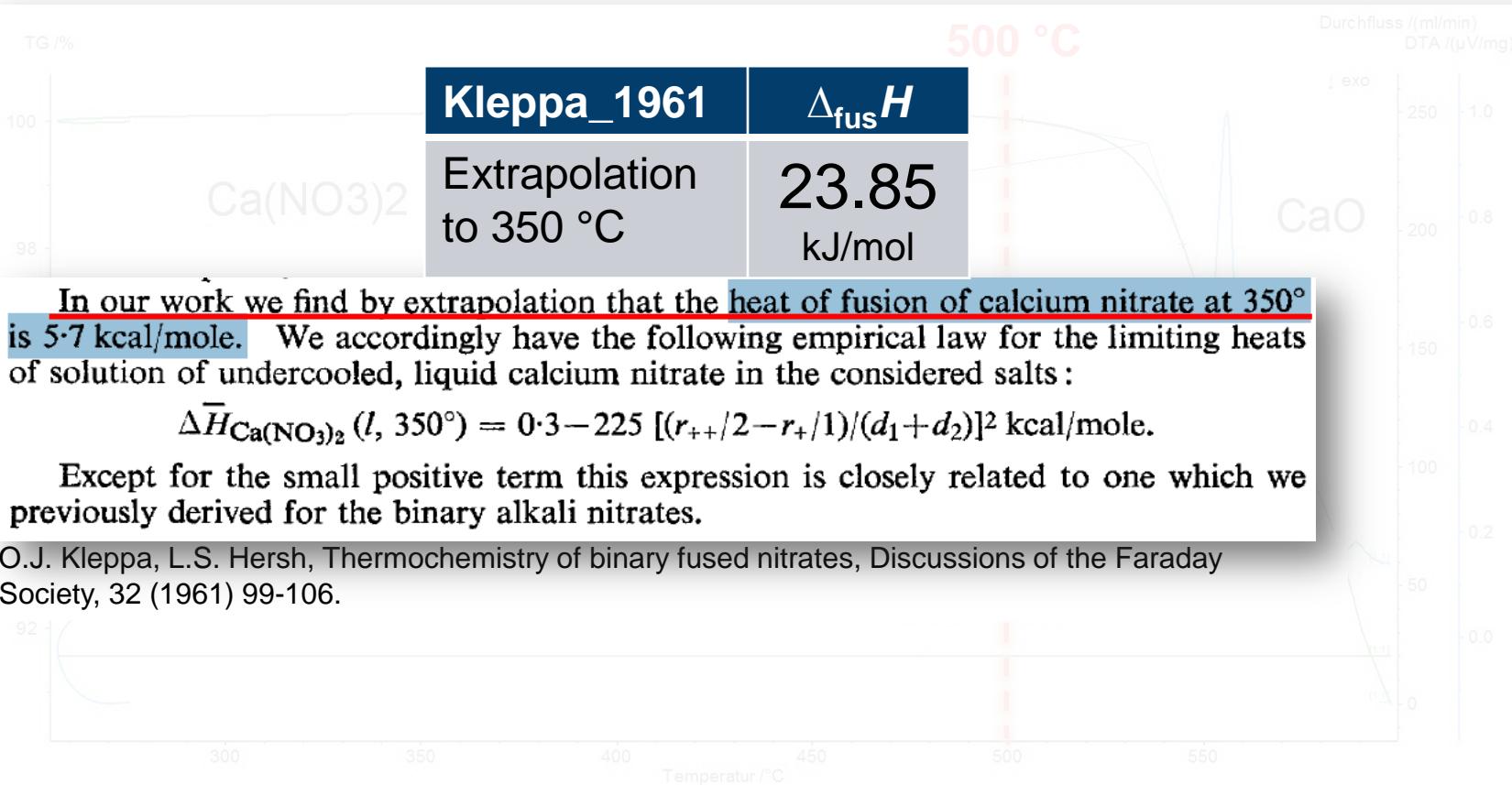


J.C. NETZSCH DSC 404C  
<http://www.netzsch.de>

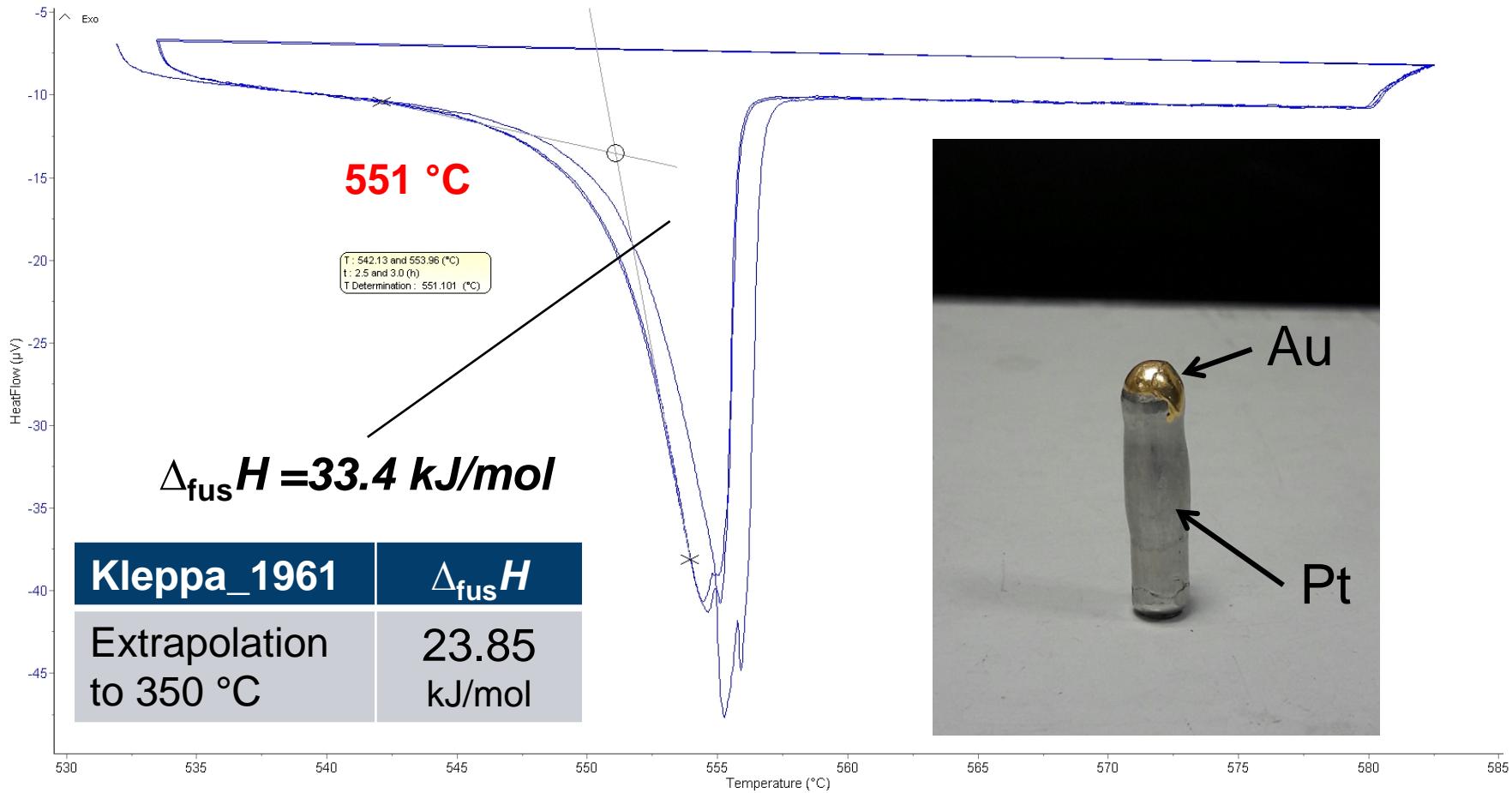
M. Sampson, A. Nissen, THERMODYNAMIC PROPERTIES OF MOLTEN NITRATE SALTS  
[http://www.osti.gov/GetRecord?osti\\_id=1000000000000000000](http://www.osti.gov/GetRecord?osti_id=1000000000000000000), (2012).

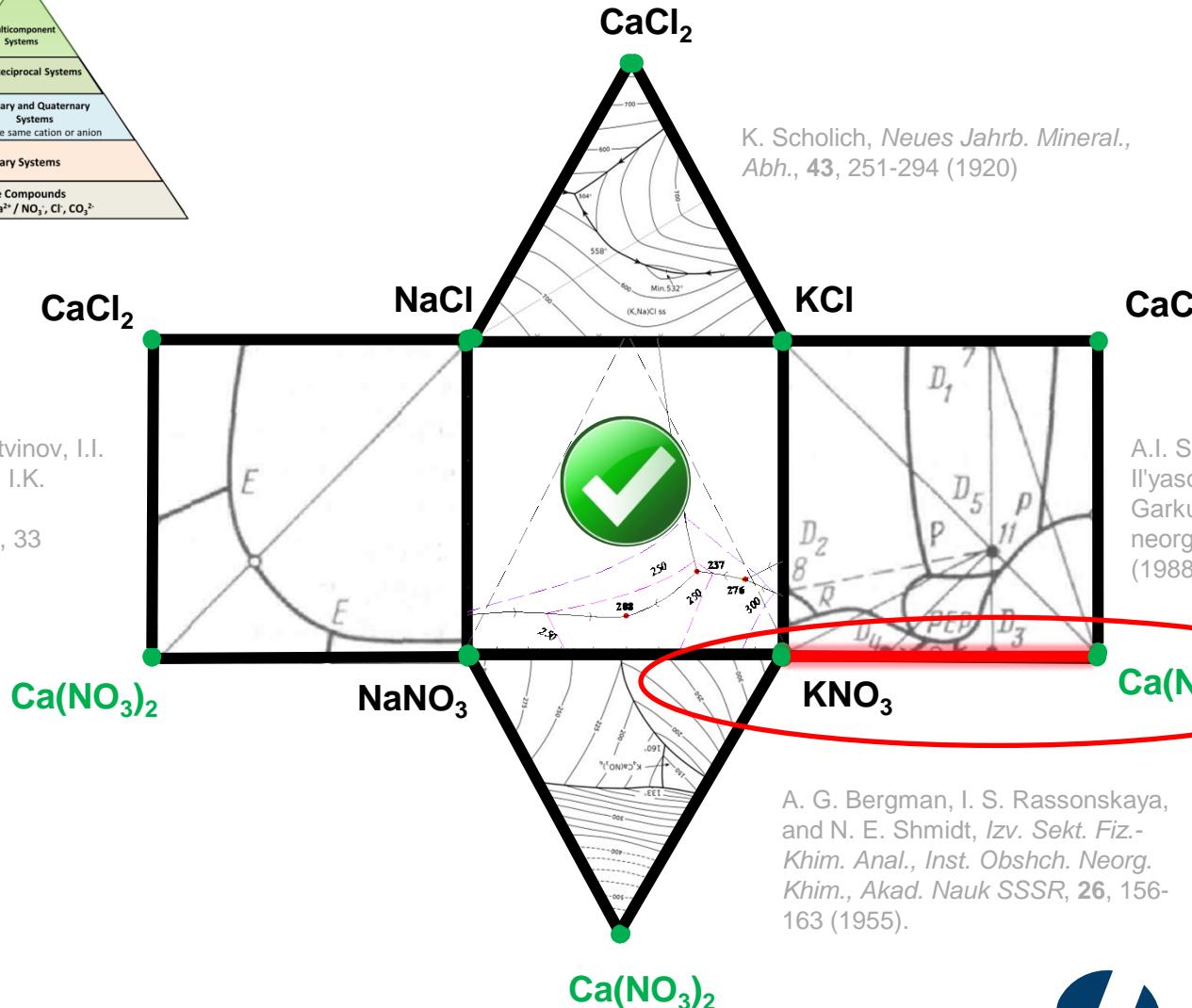
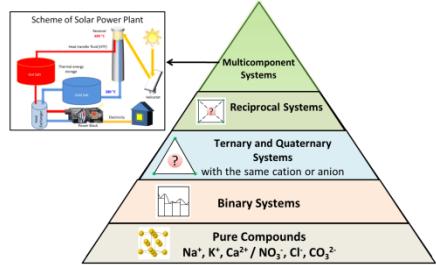
I. Barin, Thermochemical Data of Pure Substances, 3rd ed., VCH Verlag GmbH, Weinheim, Germany, 1995.

# Decomposition of Ca(NO<sub>3</sub>)<sub>2</sub>

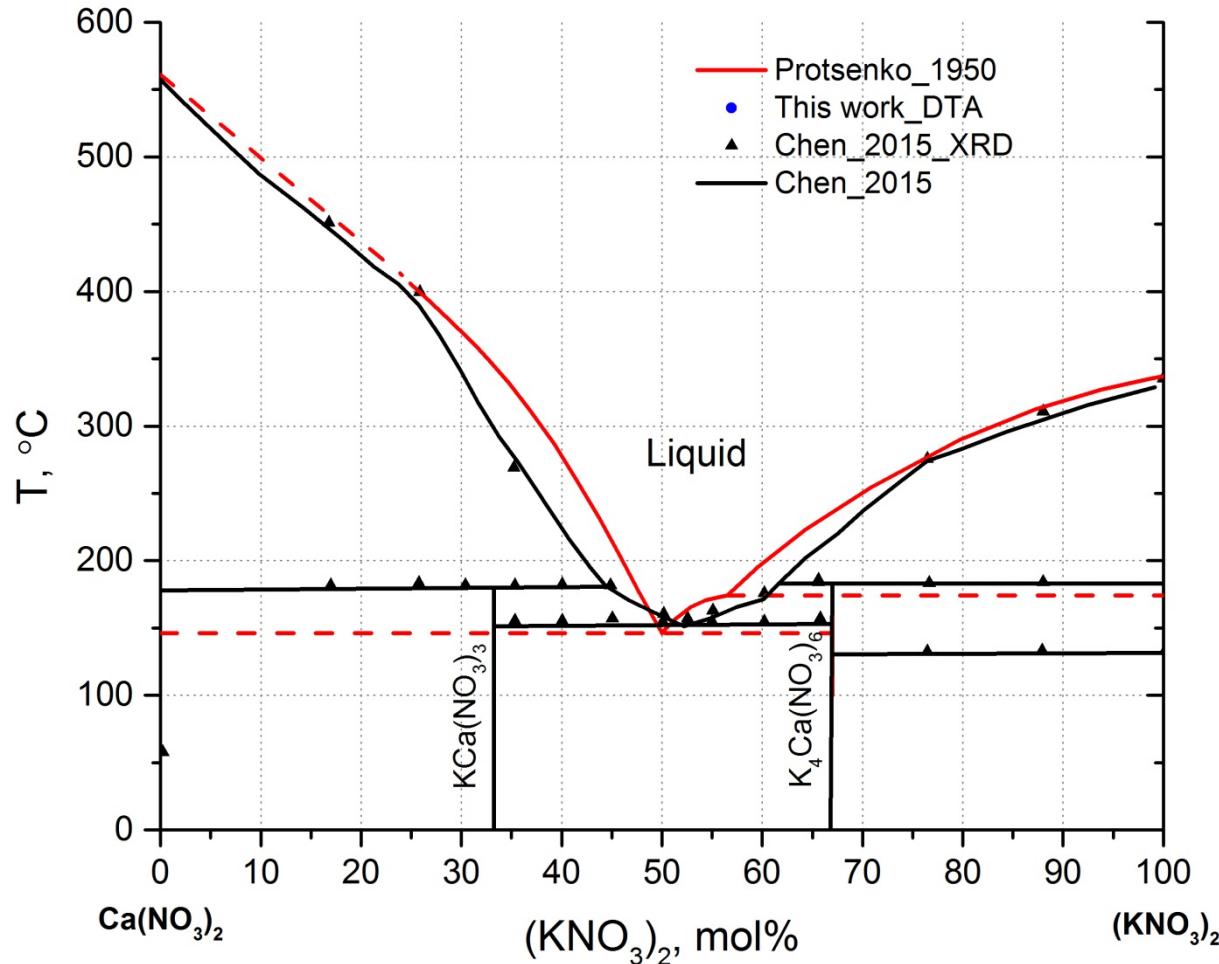


# Fusion enthalpy of Ca(NO<sub>3</sub>)<sub>2</sub>





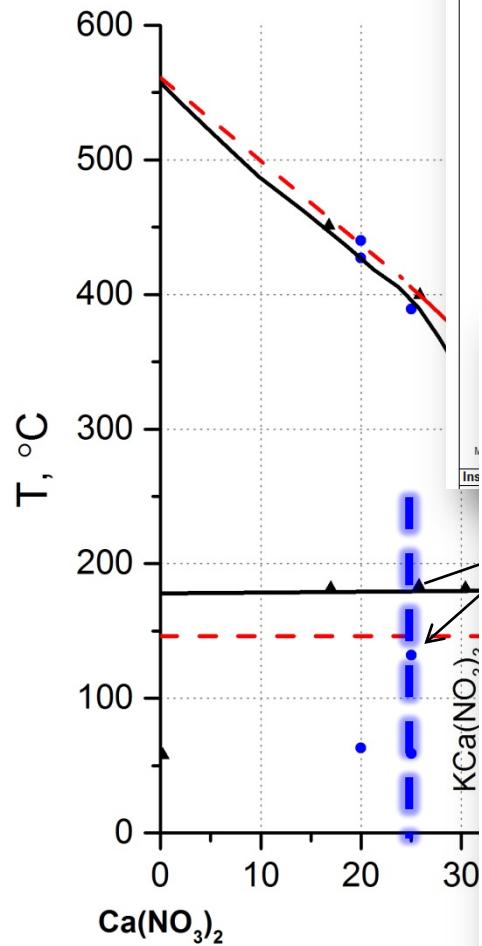
# Phase Diagram of the $\text{Ca}(\text{NO}_3)_2$ - $(\text{KNO}_3)_2$ System



J. Chen, D.W. Zeng, D.D. Li, J.T. Wang, H.J. Han, L.J. Guo, Phase diagram and thermal stability of  $\text{KNO}_3$ - $\text{Ca}(\text{NO}_3)_2$  binary system, Inorg. Chem. Ind. 47 (11), (2015) 38–41.

P.I. Protsenko, A.G. Bergman, Ternary system of fused nitrates of calcium, potassium, and sodium, Zhurnal Obshchei Khimii, 20 (1950) 1365-1375.

# Phase Diagram of the Ca-K-N system



J. Chen, D.W. Zeng, D.D. Li, J.T. Wang, H.J. Han, L.J. Guo  
47 (11), (2015) 38–41.

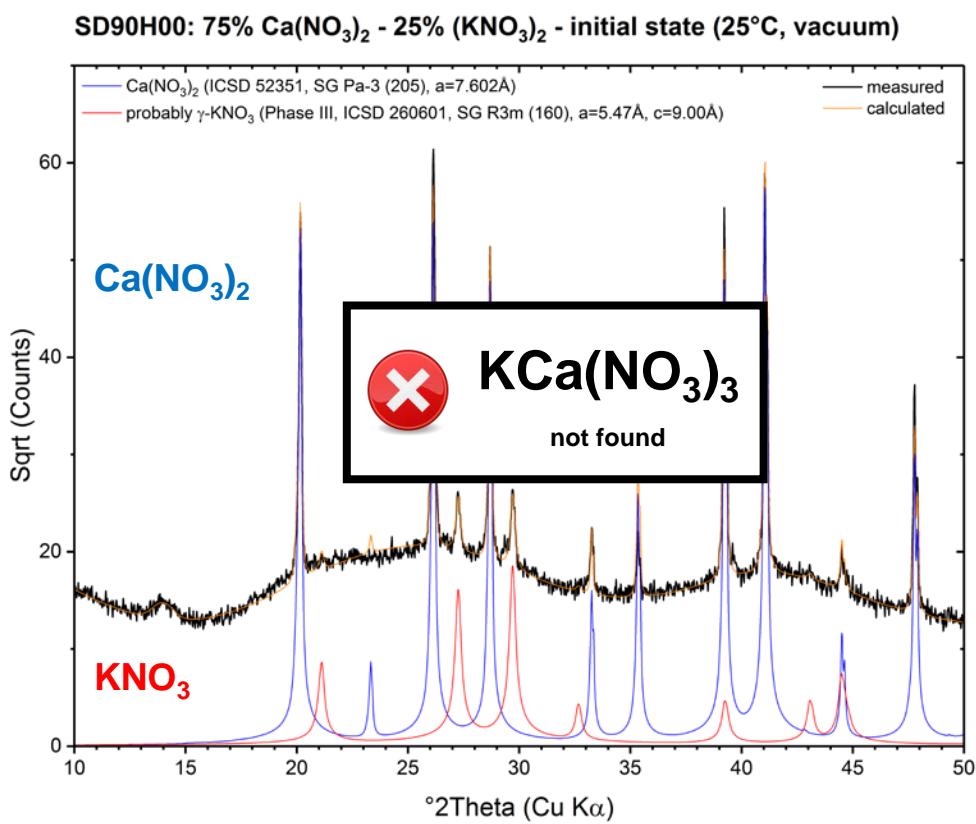
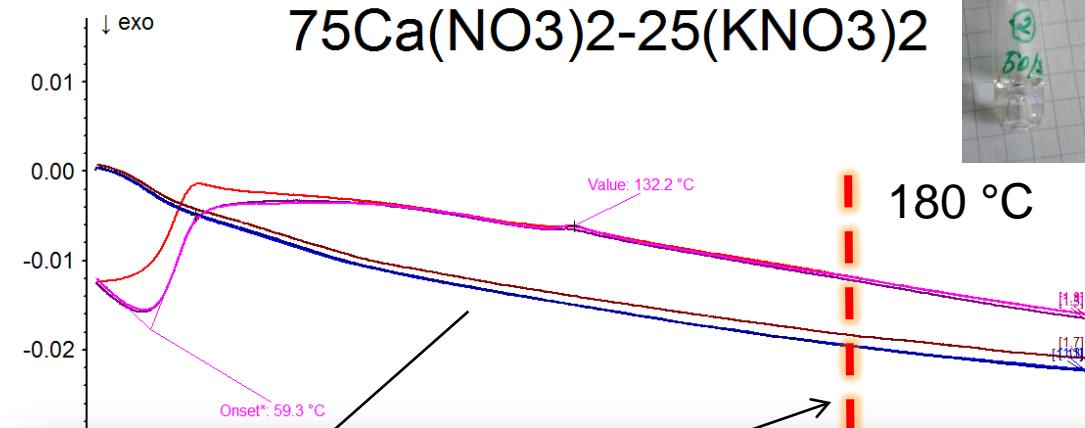
P.I. Protsenko, A.G. Bergman, Ternary system of fused nitrates. Obshchei Khimii, 20 (1950) 1365-1375.

Mitglied der Helmholtz-Gemeinschaft

15/01/2019

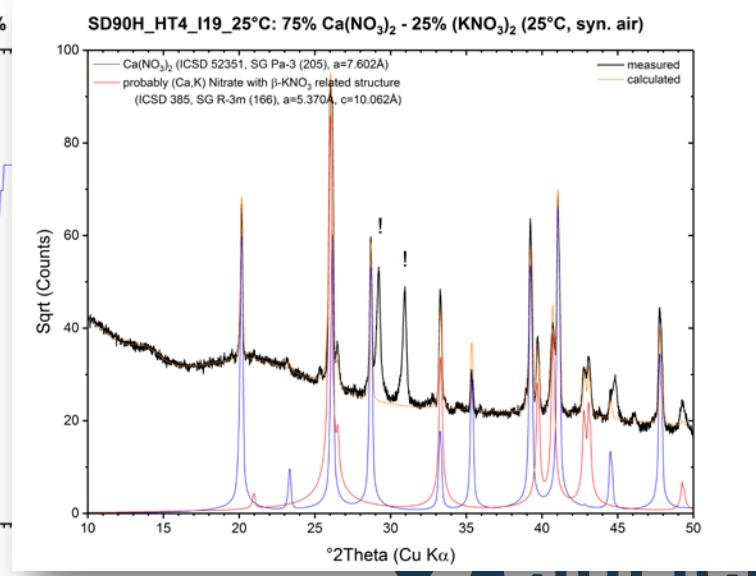
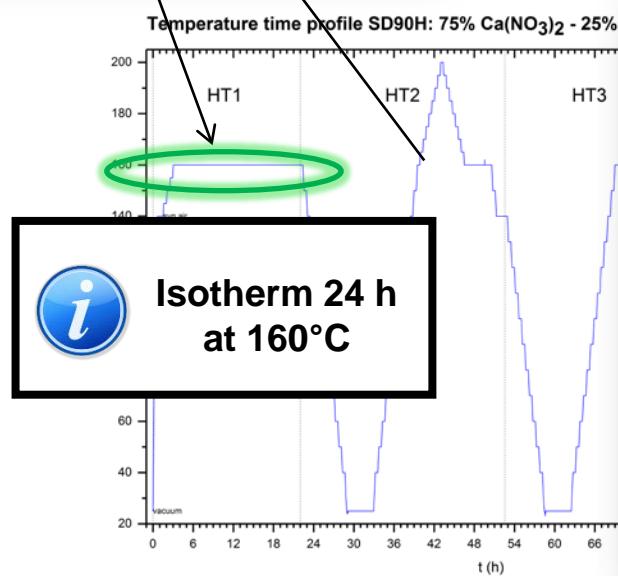
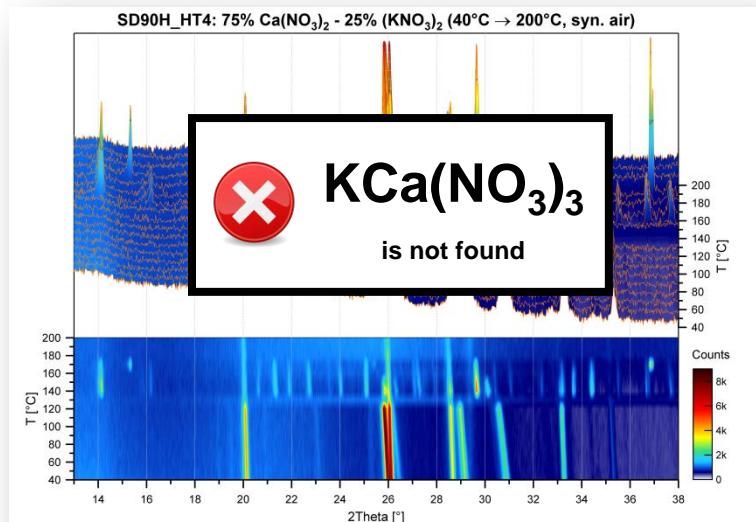
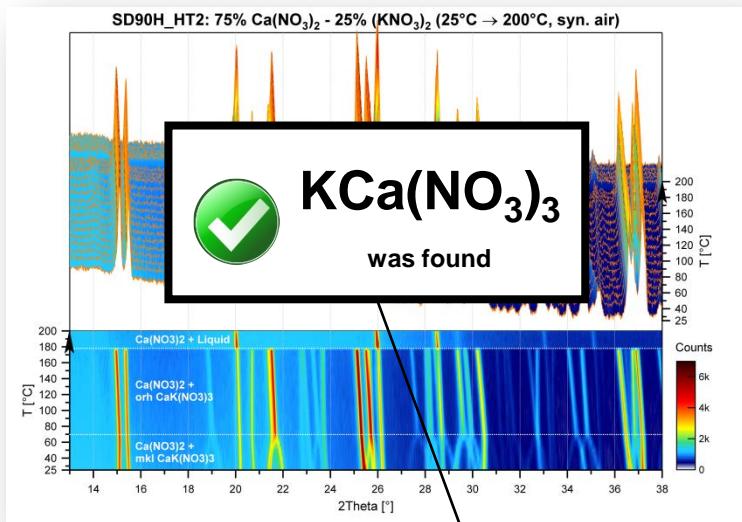
DSC / ( $\mu\text{V}/\text{mg}$ )

75Ca(NO<sub>3</sub>)<sub>2</sub>-25(KNO<sub>3</sub>)<sub>2</sub>

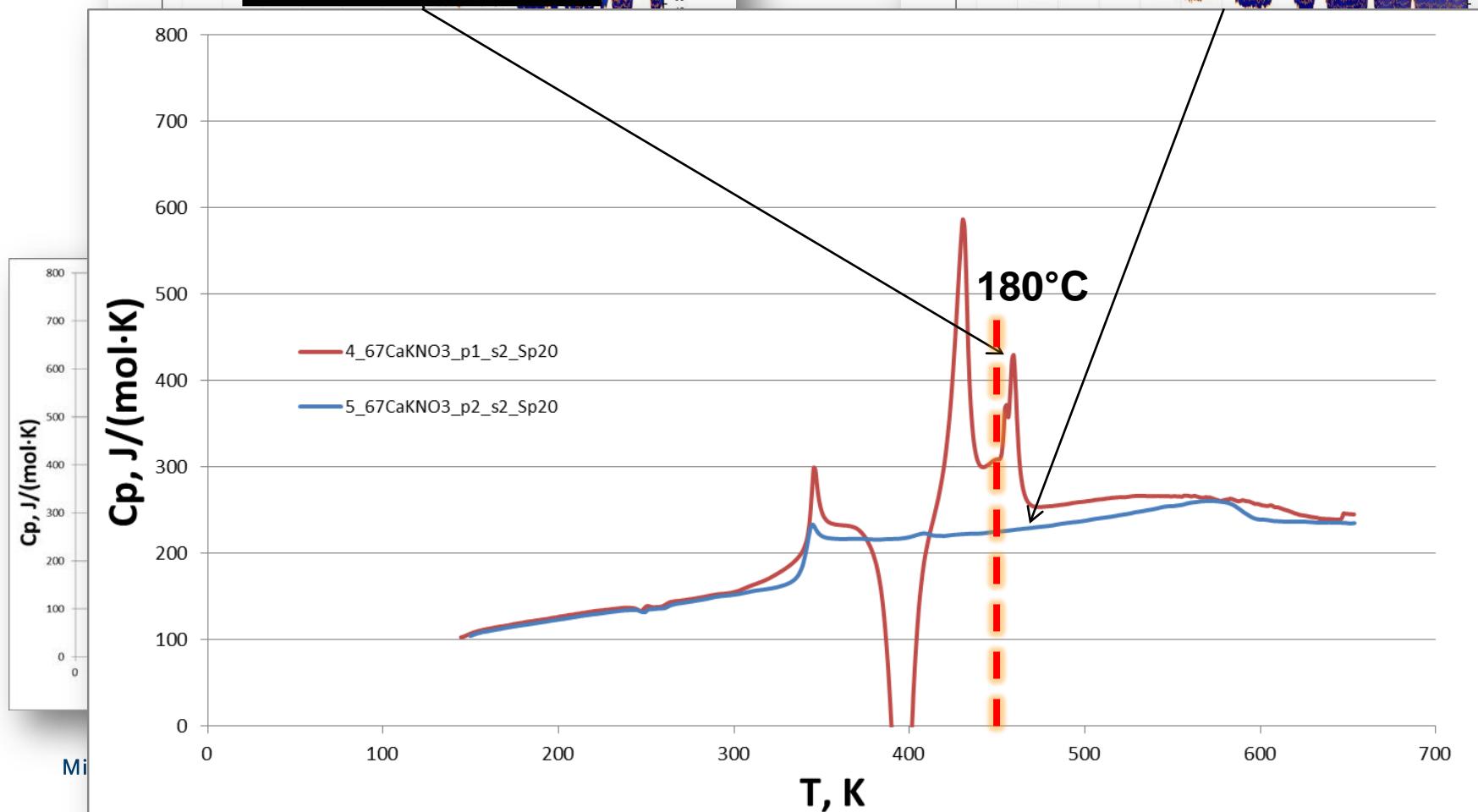
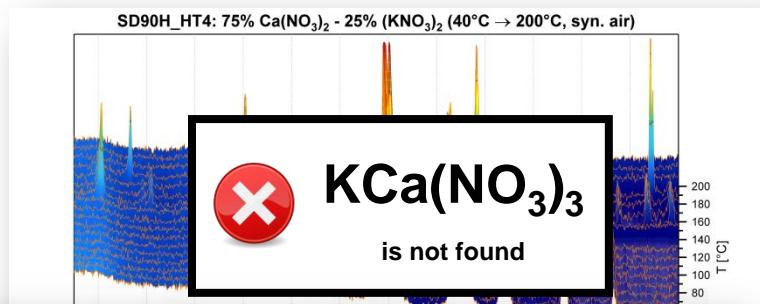
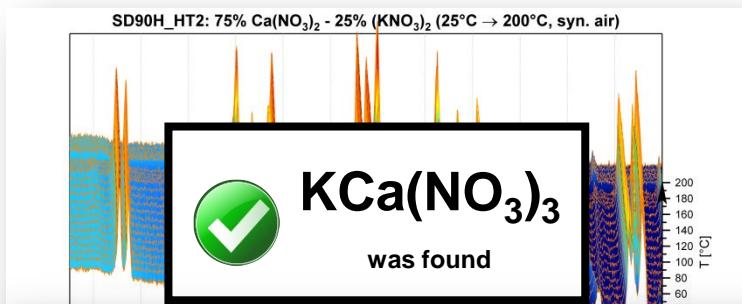


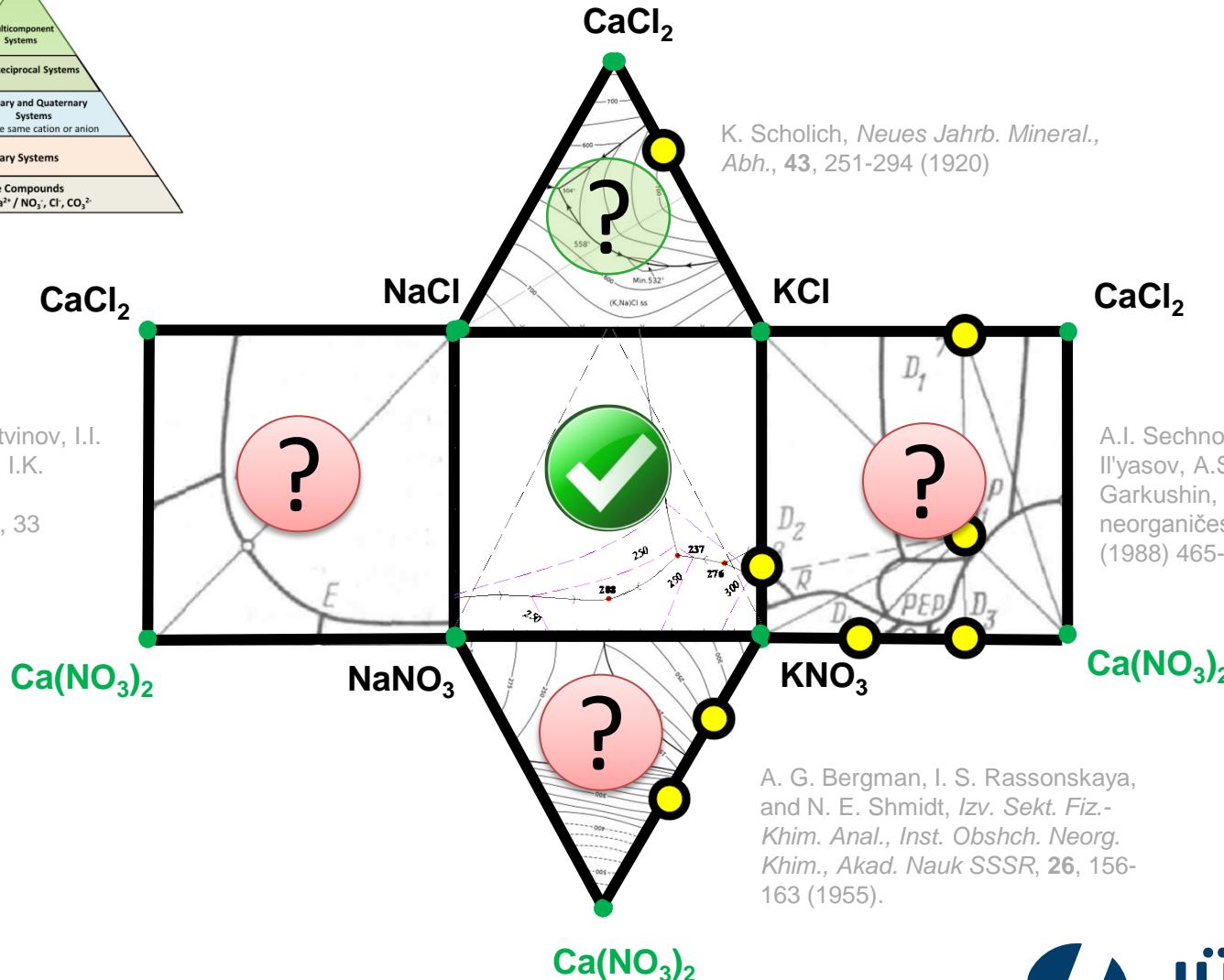
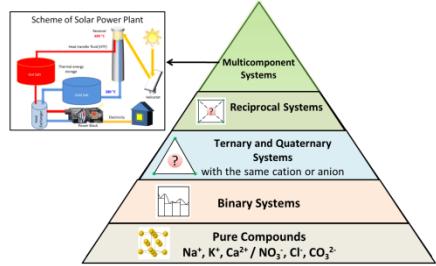
Forschungszentrum

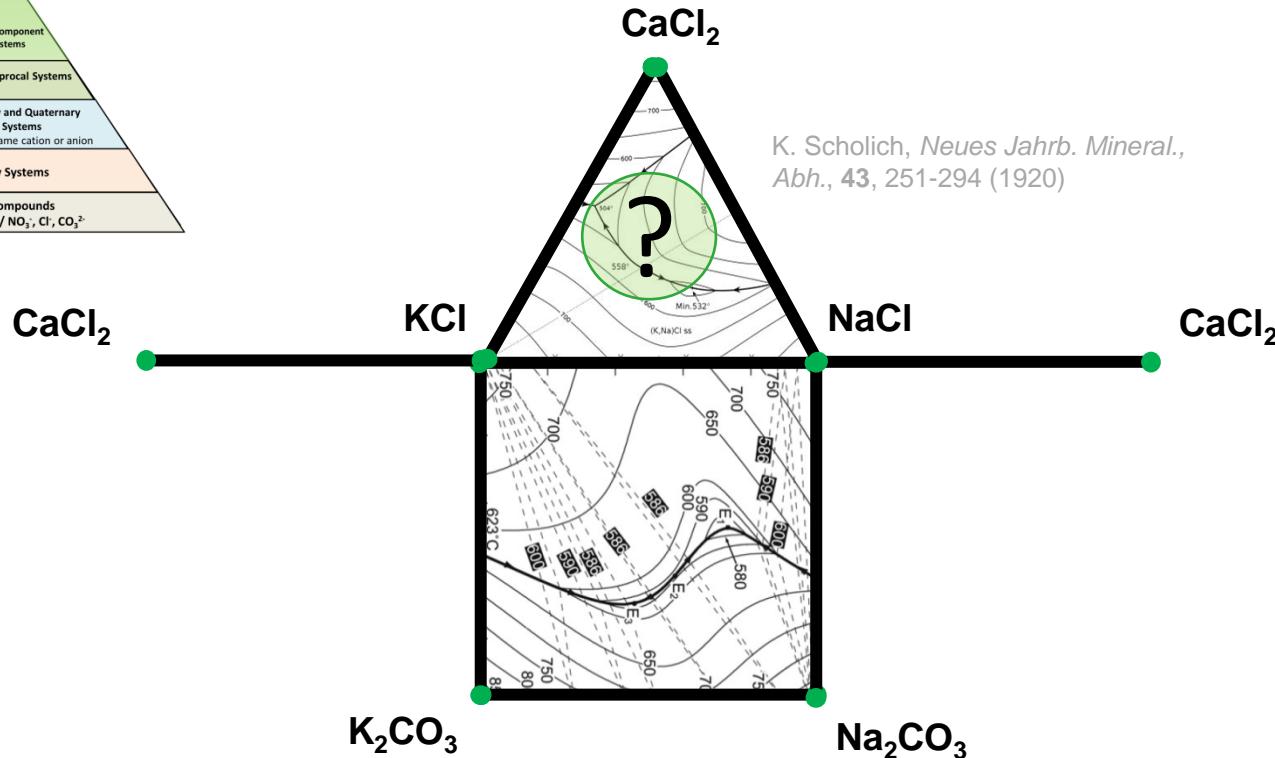
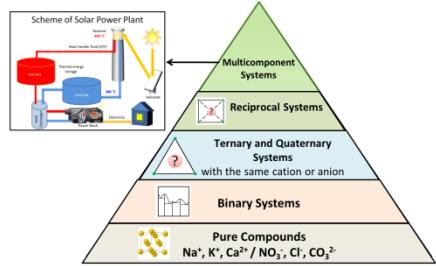
# HTXRD Measurements of $\text{Ca}(\text{NO}_3)_2\text{-}(\text{KNO}_3)_2$

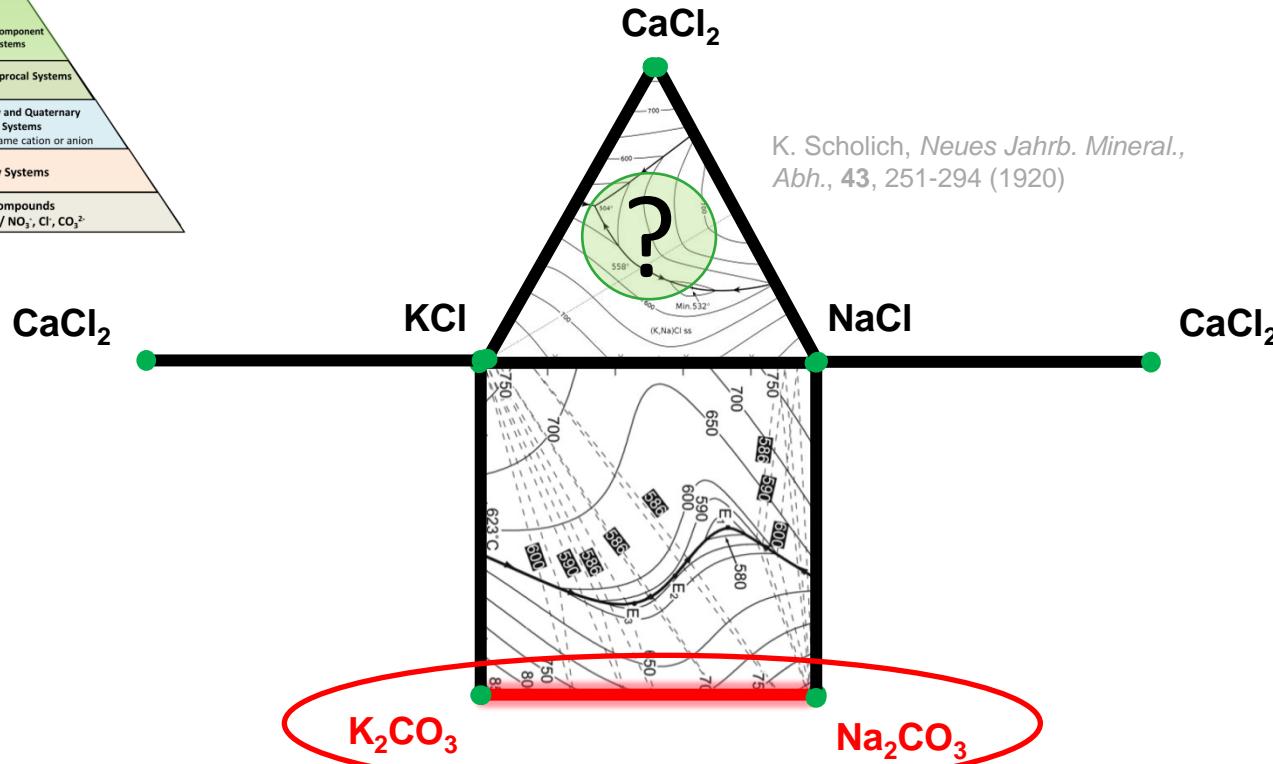
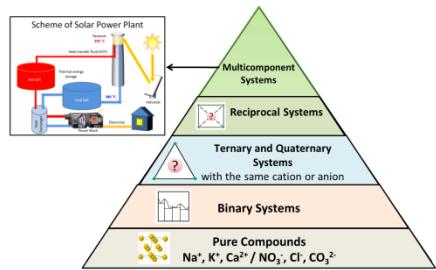


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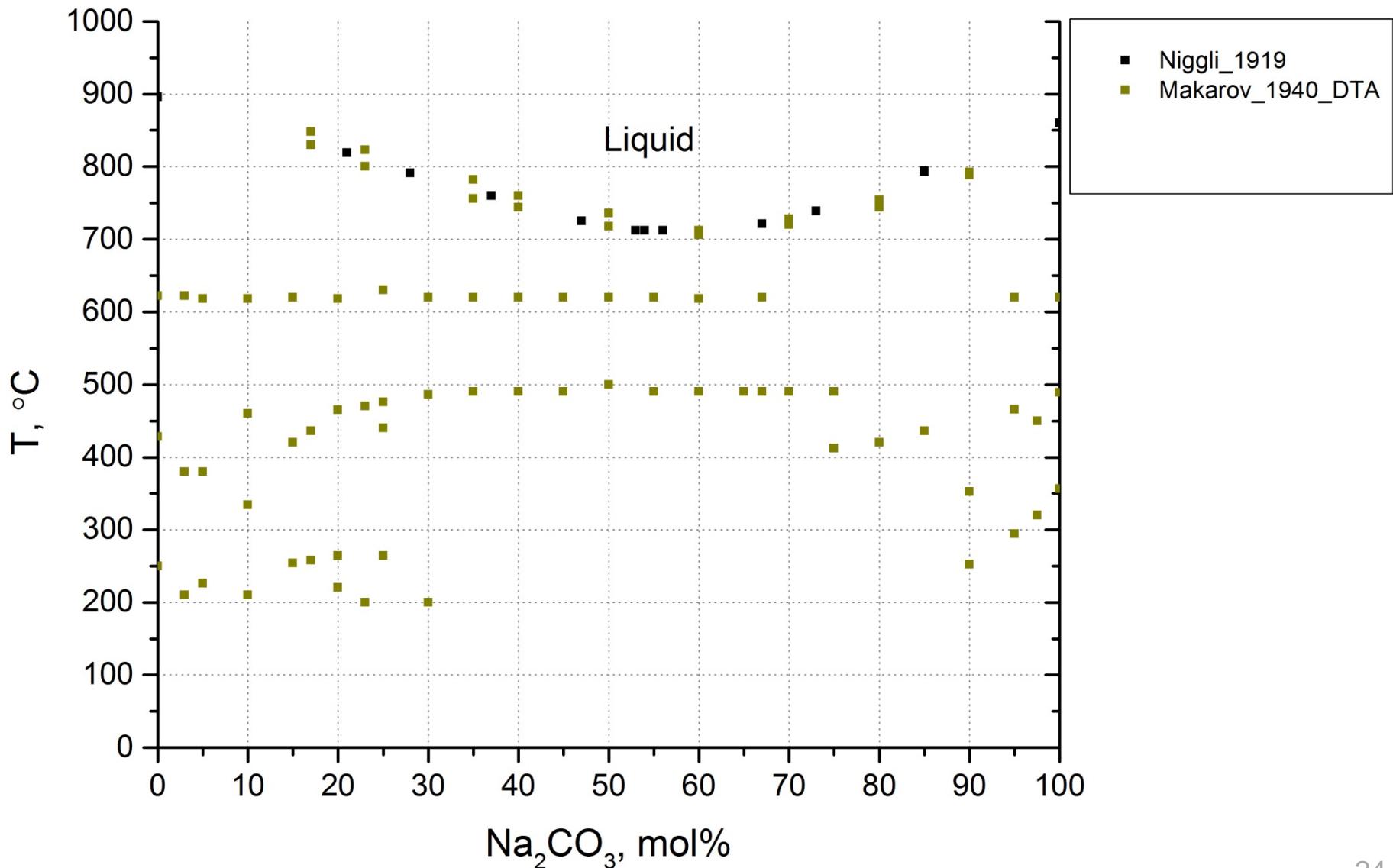




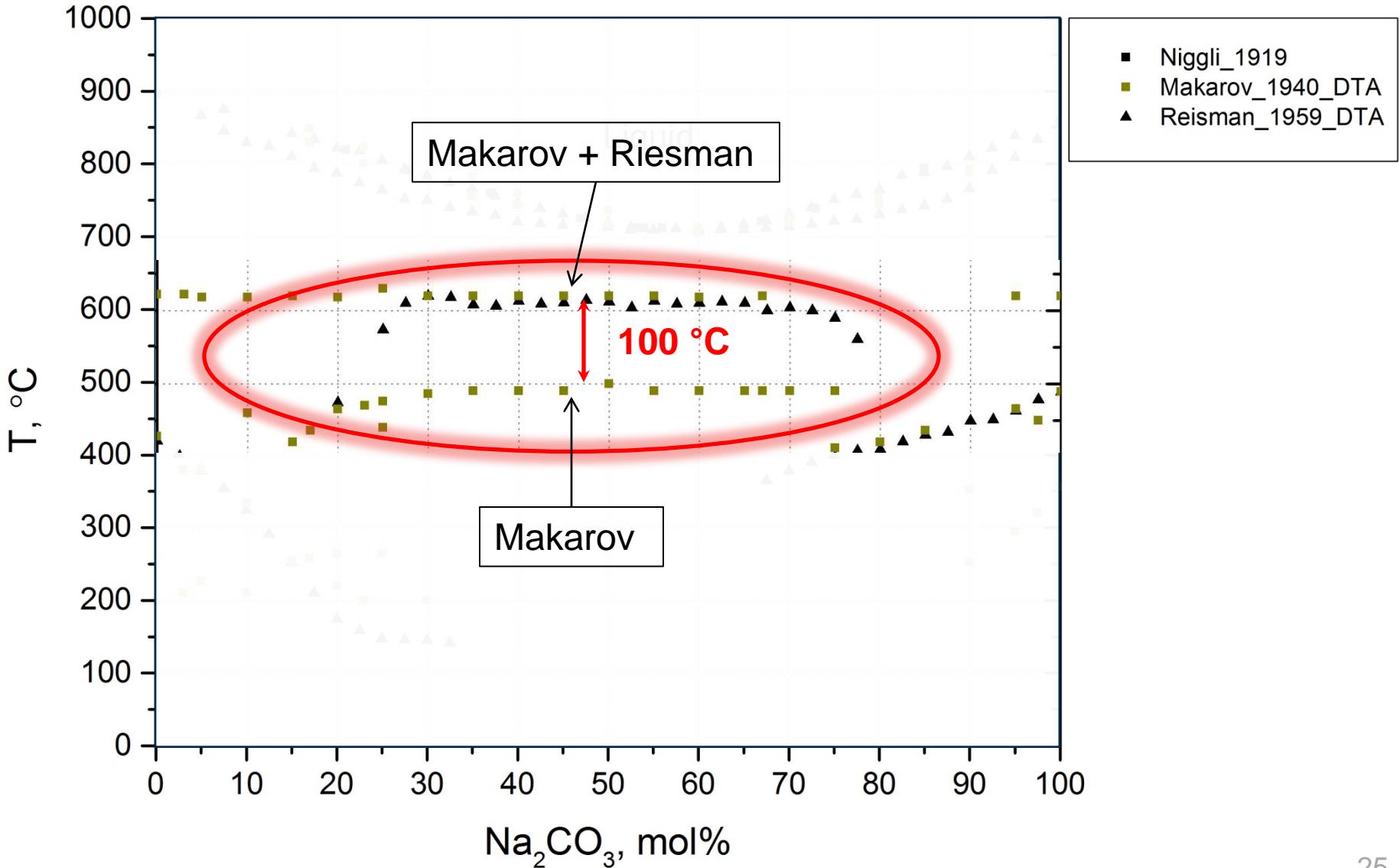


J. Yaokawa, K. Oikawa, K. Anzai,  
Thermodynamic assessment of the  
KCl–K<sub>2</sub>CO<sub>3</sub>–NaCl–Na<sub>2</sub>CO<sub>3</sub> system  
Calphad, 31 (2007) 155–163.

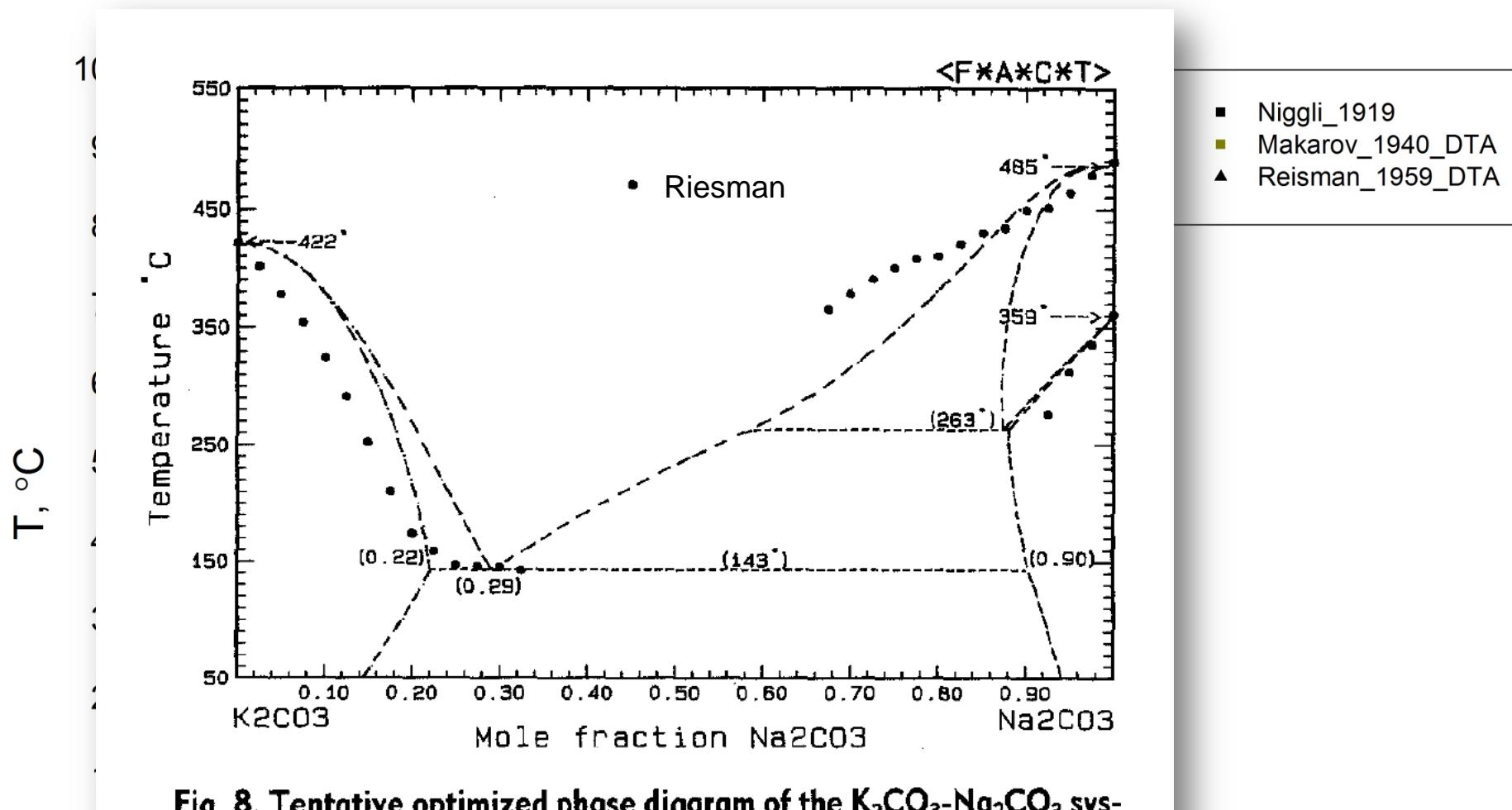
# Phase Diagram of $\text{K}_2\text{CO}_3$ - $\text{Na}_2\text{CO}_3$



# $K_2CO_3$ - $Na_2CO_3$ Phase Diagram



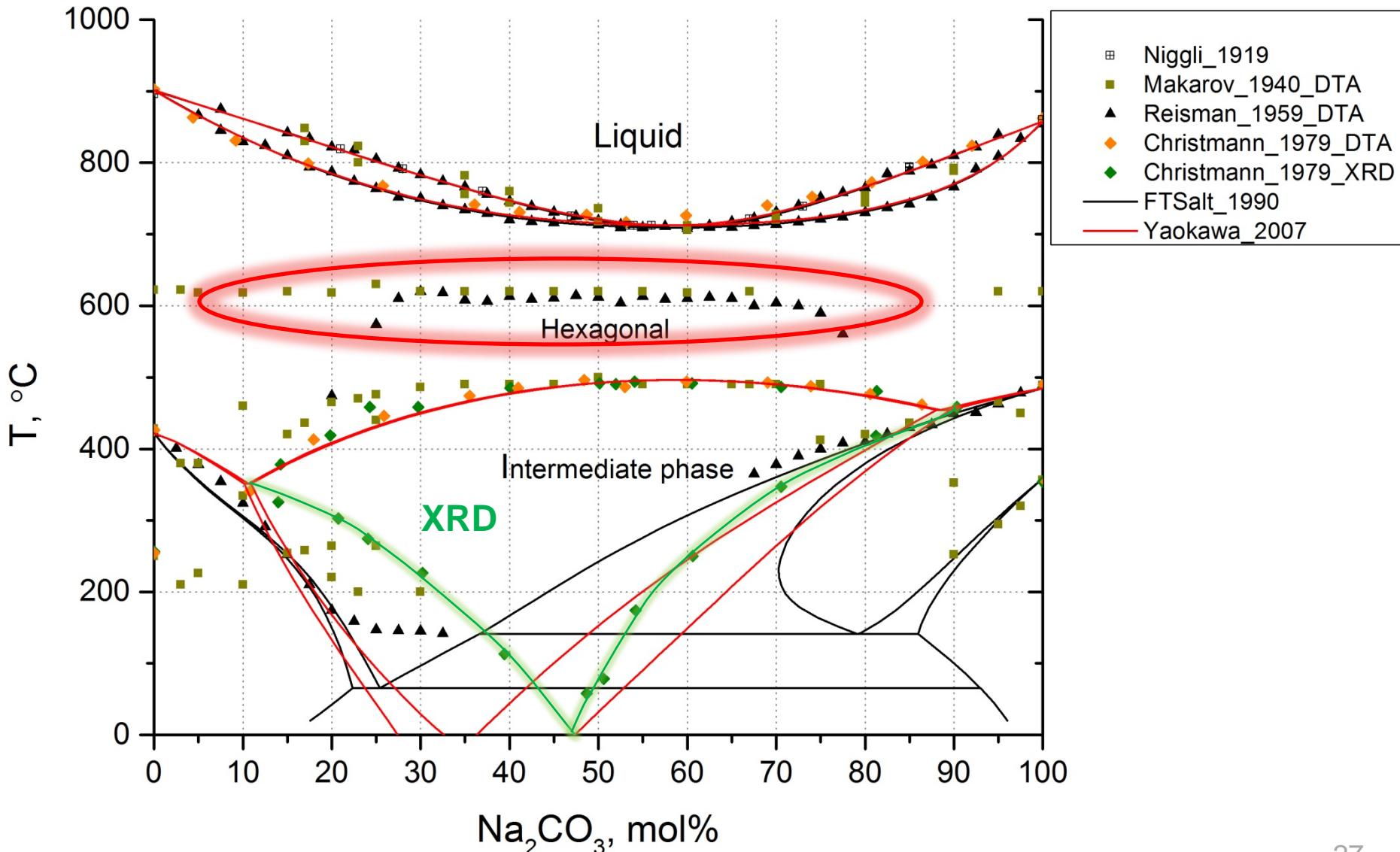
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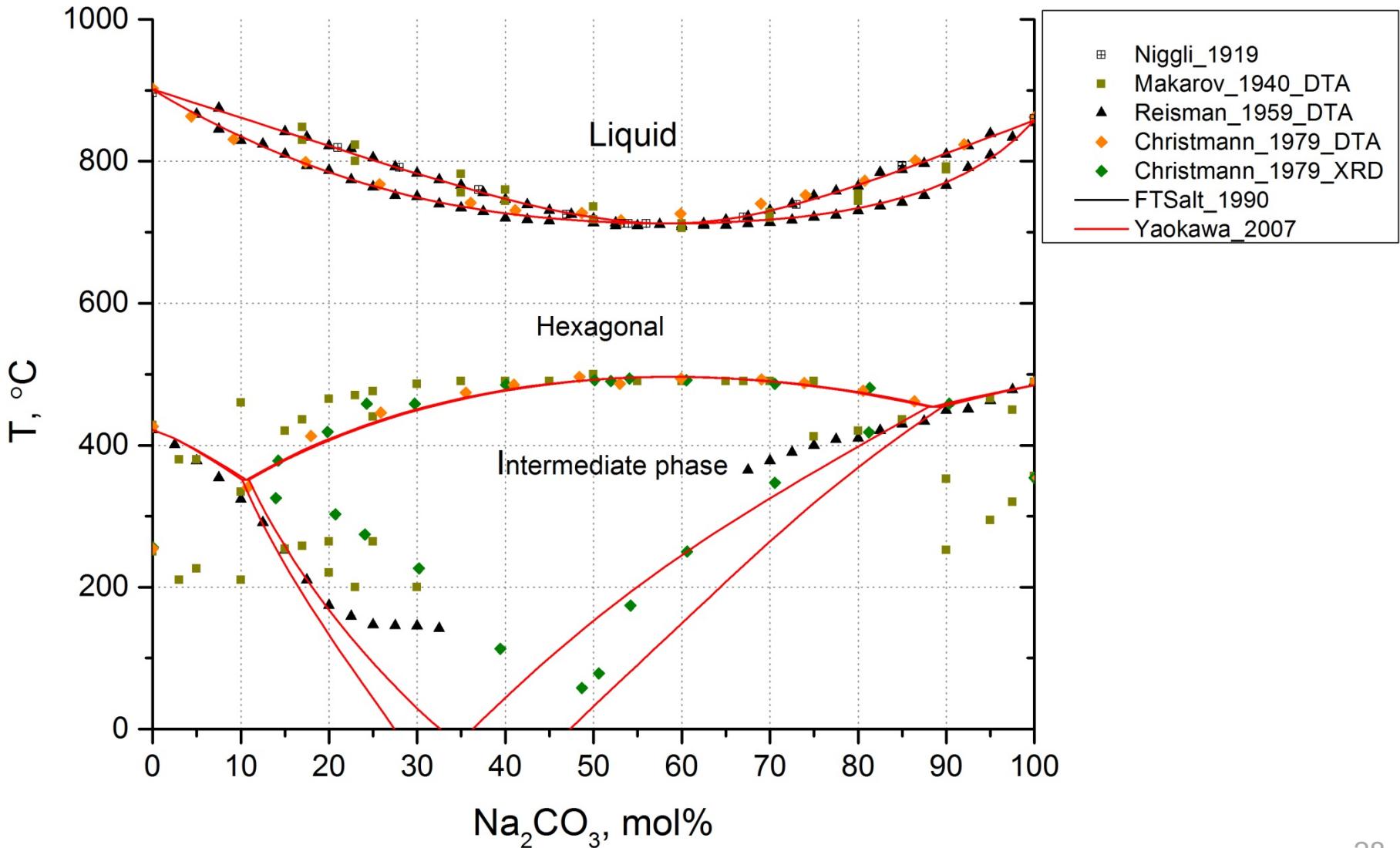
**Fig. 8. Tentative optimized phase diagram of the  $K_2CO_3$ - $Na_2CO_3$  system-subsolidus.**

Y. Dessureault, J. Sangster, A.D. Pelton, Coupled Phase Diagram/Thermodynamic Analysis of the Nine Common-Ion Binary Systems Involving the Carbonates and Sulfates of Lithium, Sodium, and Potassium, Journal of The Electrochemical Society, 137 (1990) 2941-2950.

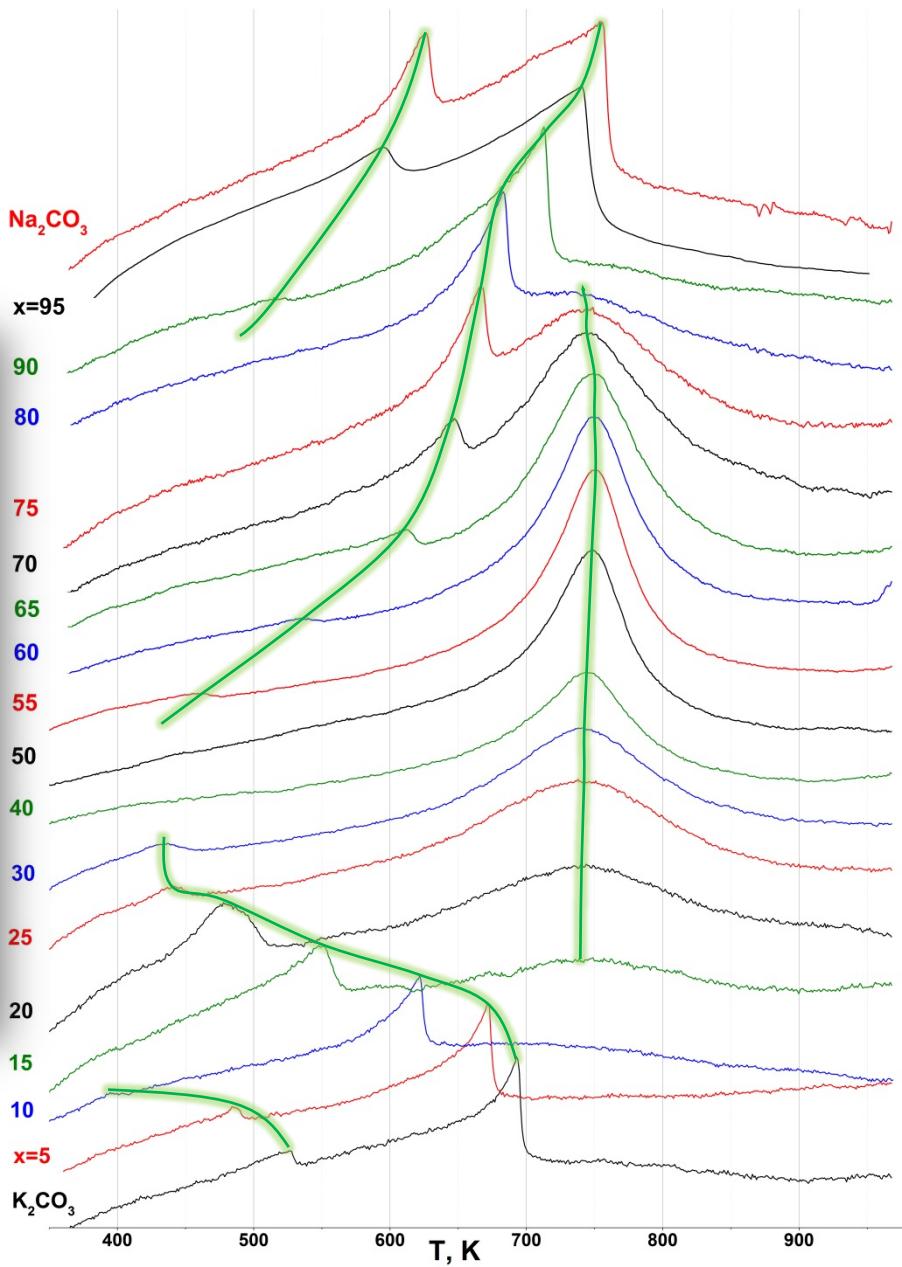
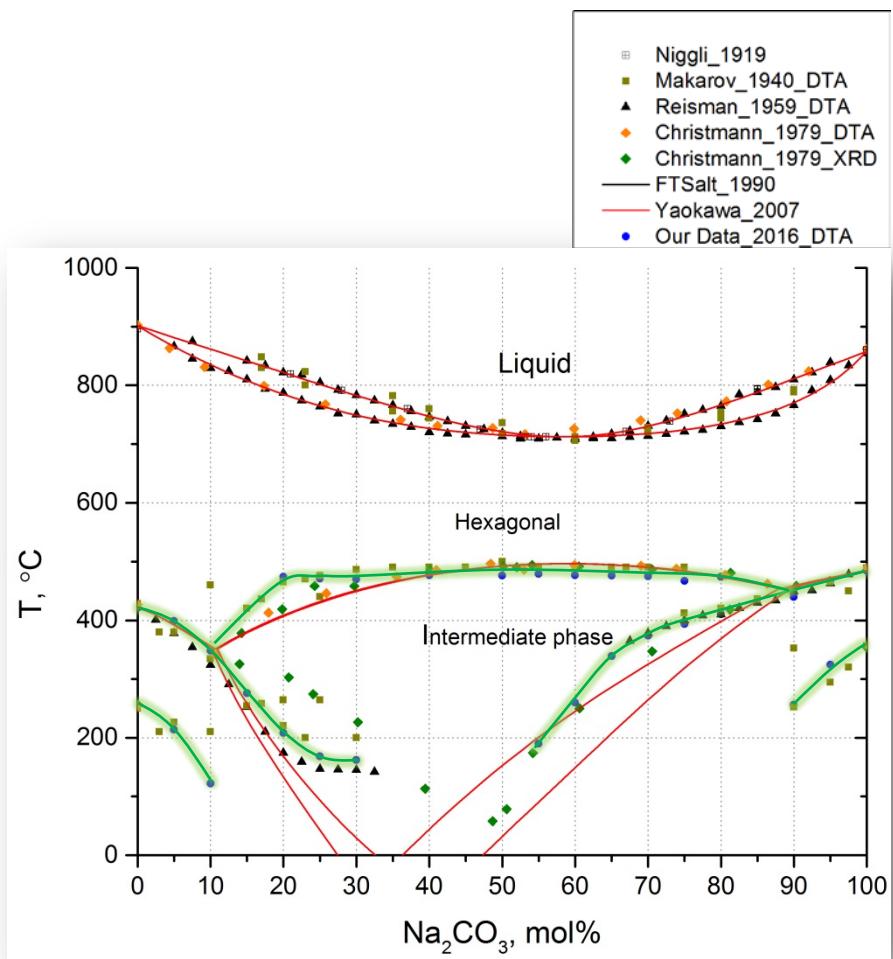
# $\text{K}_2\text{CO}_3$ - $\text{Na}_2\text{CO}_3$ Phase Diagram



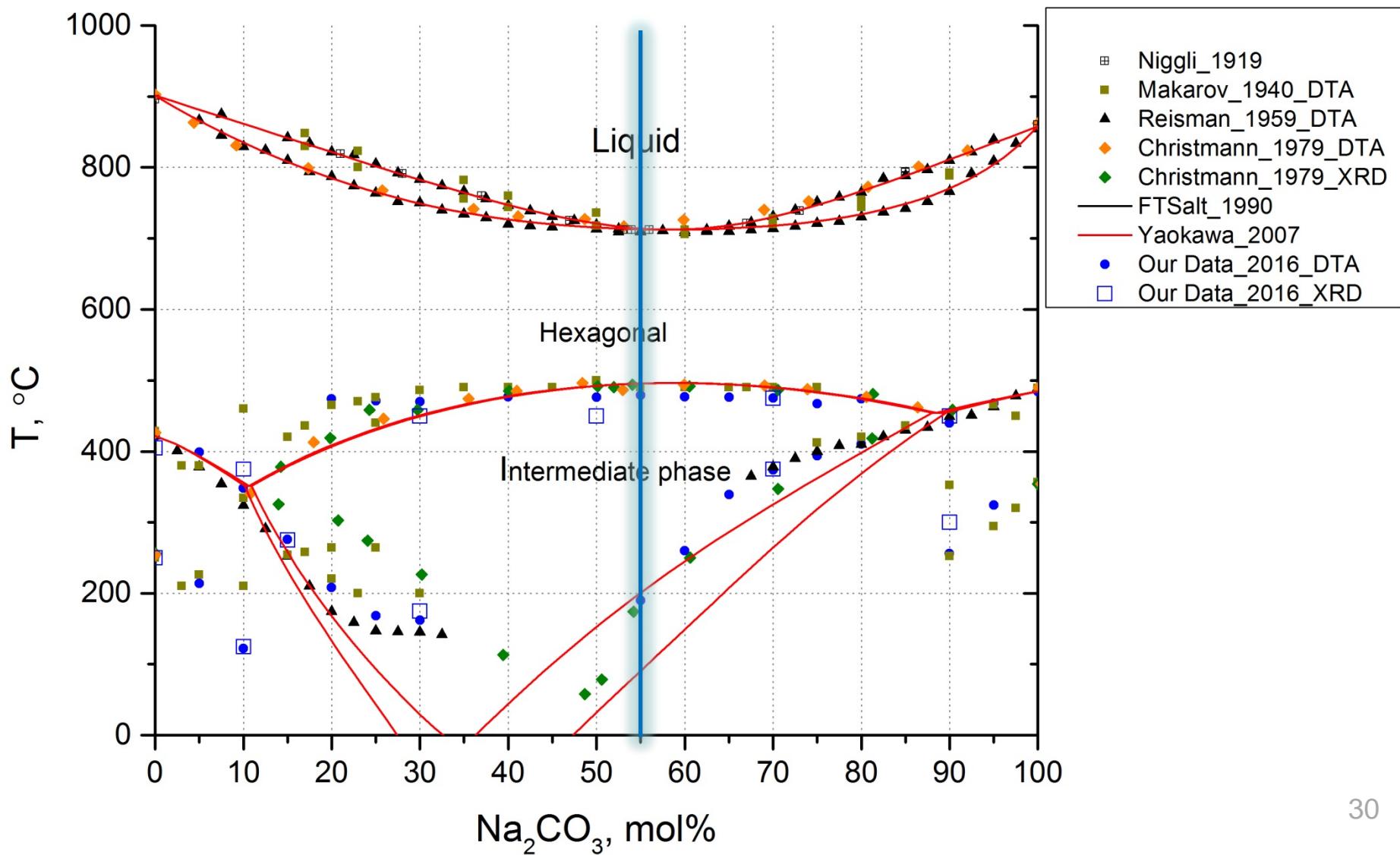
# $\text{K}_2\text{CO}_3$ - $\text{Na}_2\text{CO}_3$ Phase Diagram



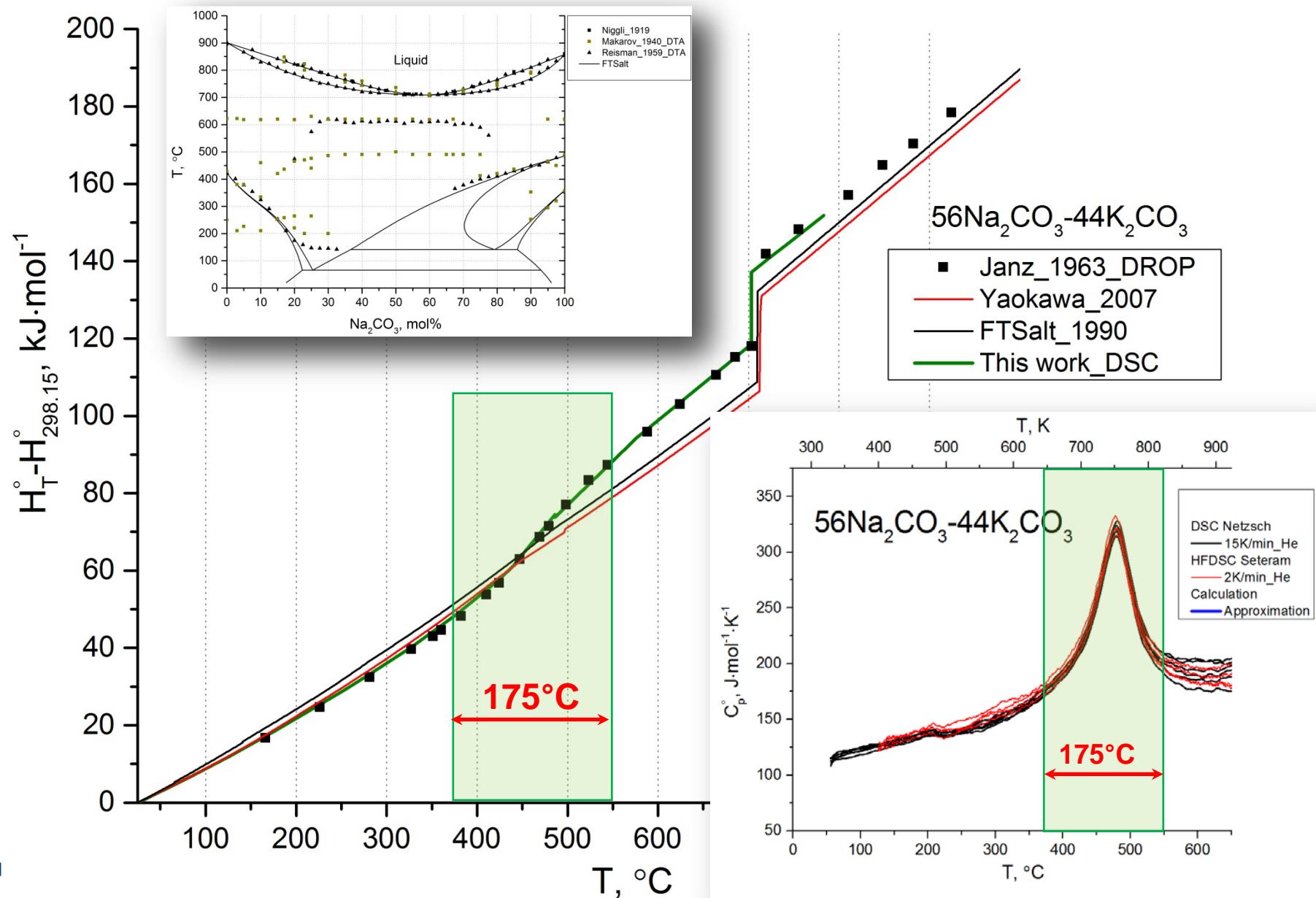
# Our DTA measurements



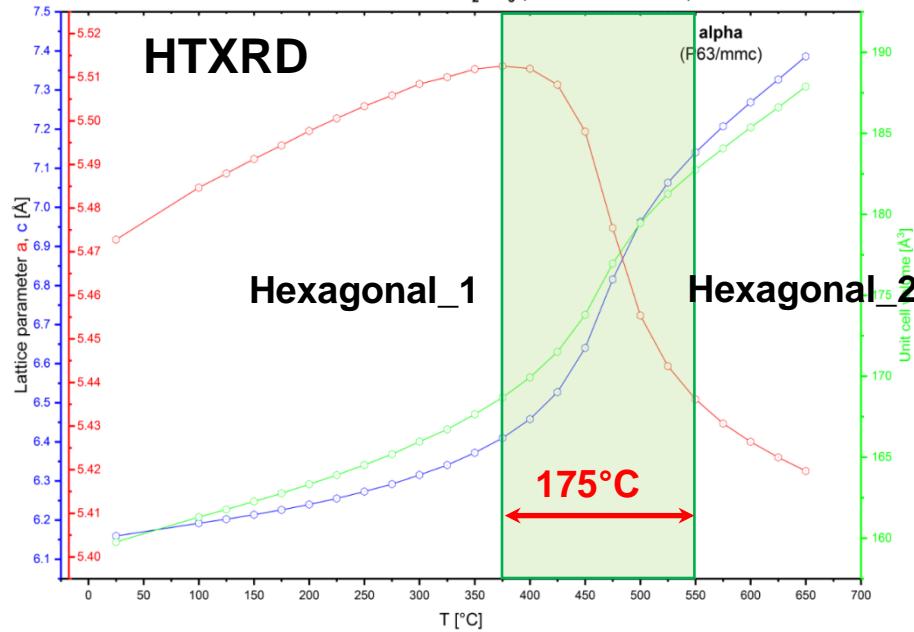
# $K_2CO_3$ - $Na_2CO_3$ Phase Diagram



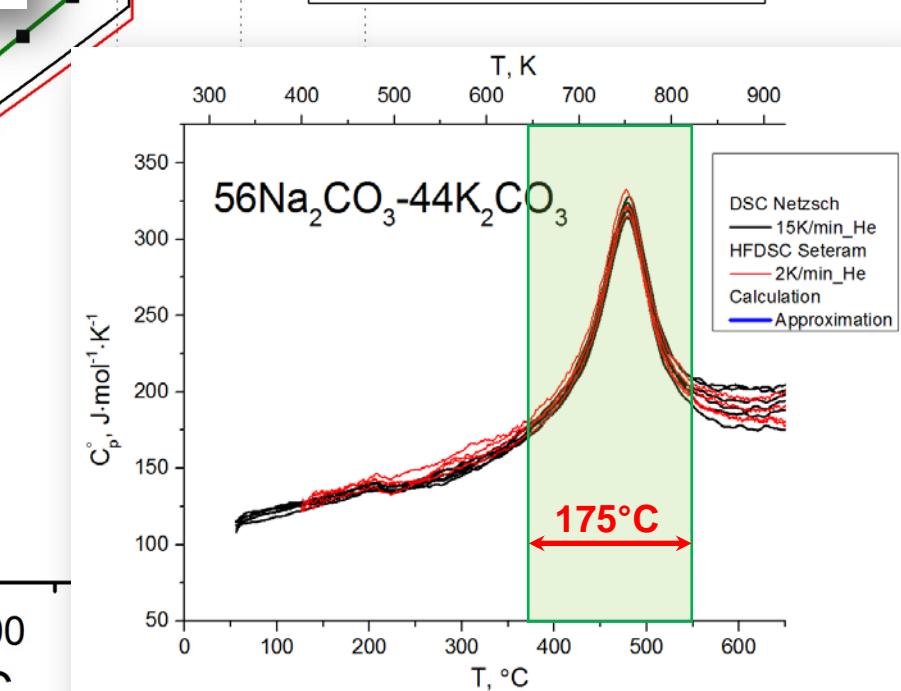
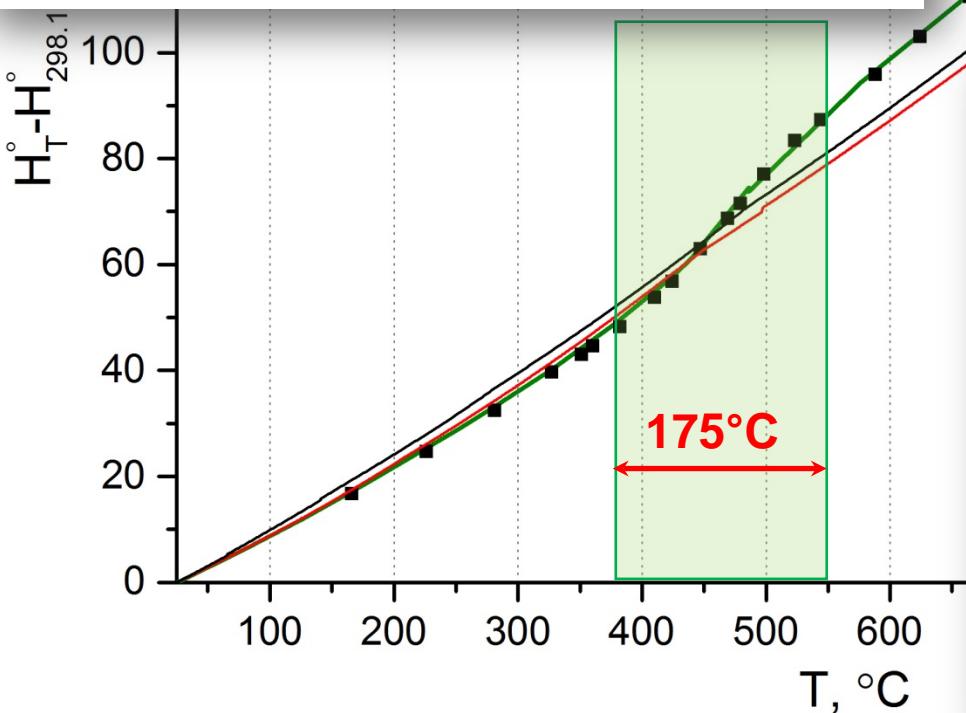
# 44K<sub>2</sub>CO<sub>3</sub>-56Na<sub>2</sub>CO<sub>3</sub> Enthalpy Increment



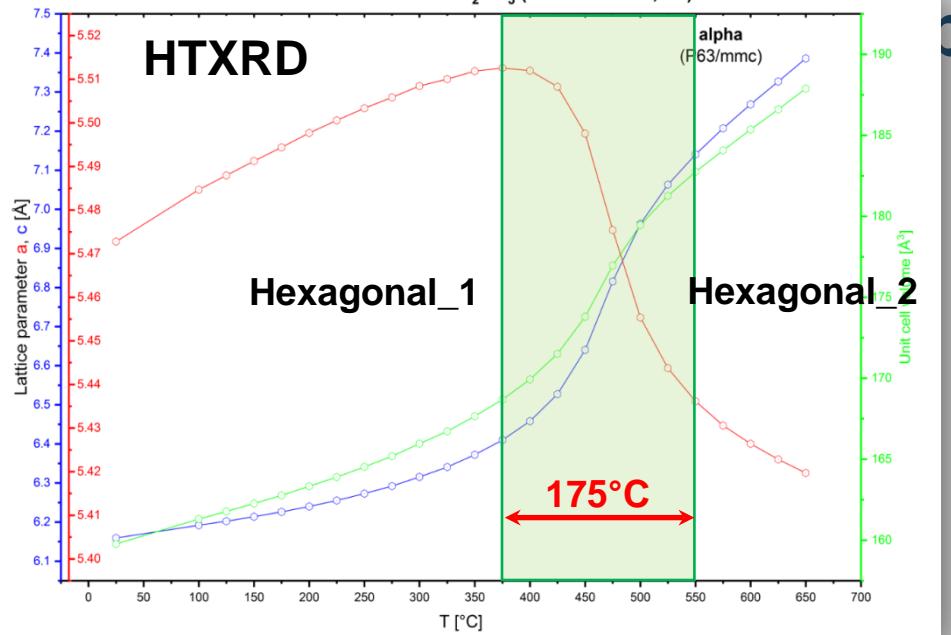
DD29A1: 50 Na<sub>2</sub>CO<sub>3</sub> - 50 K<sub>2</sub>CO<sub>3</sub> (650°C → 25°C, air)



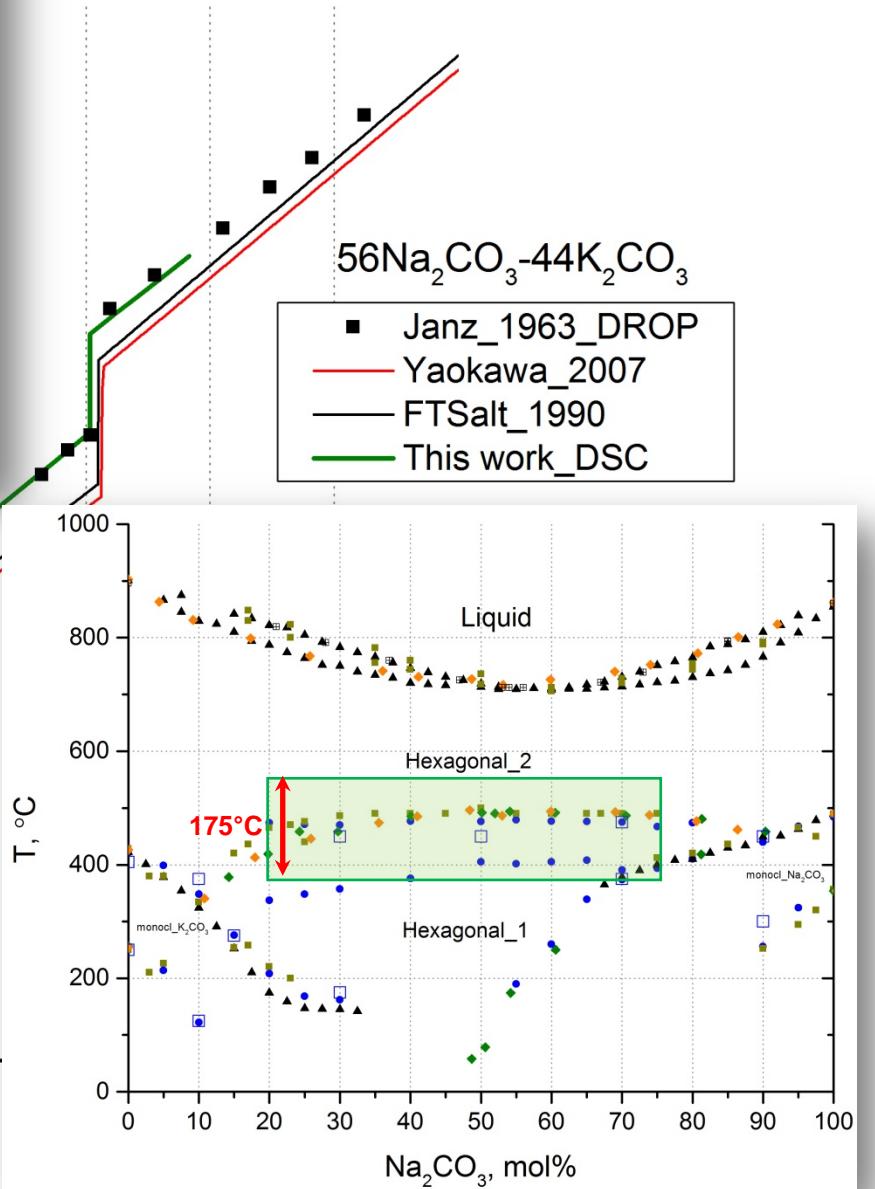
# by Increment



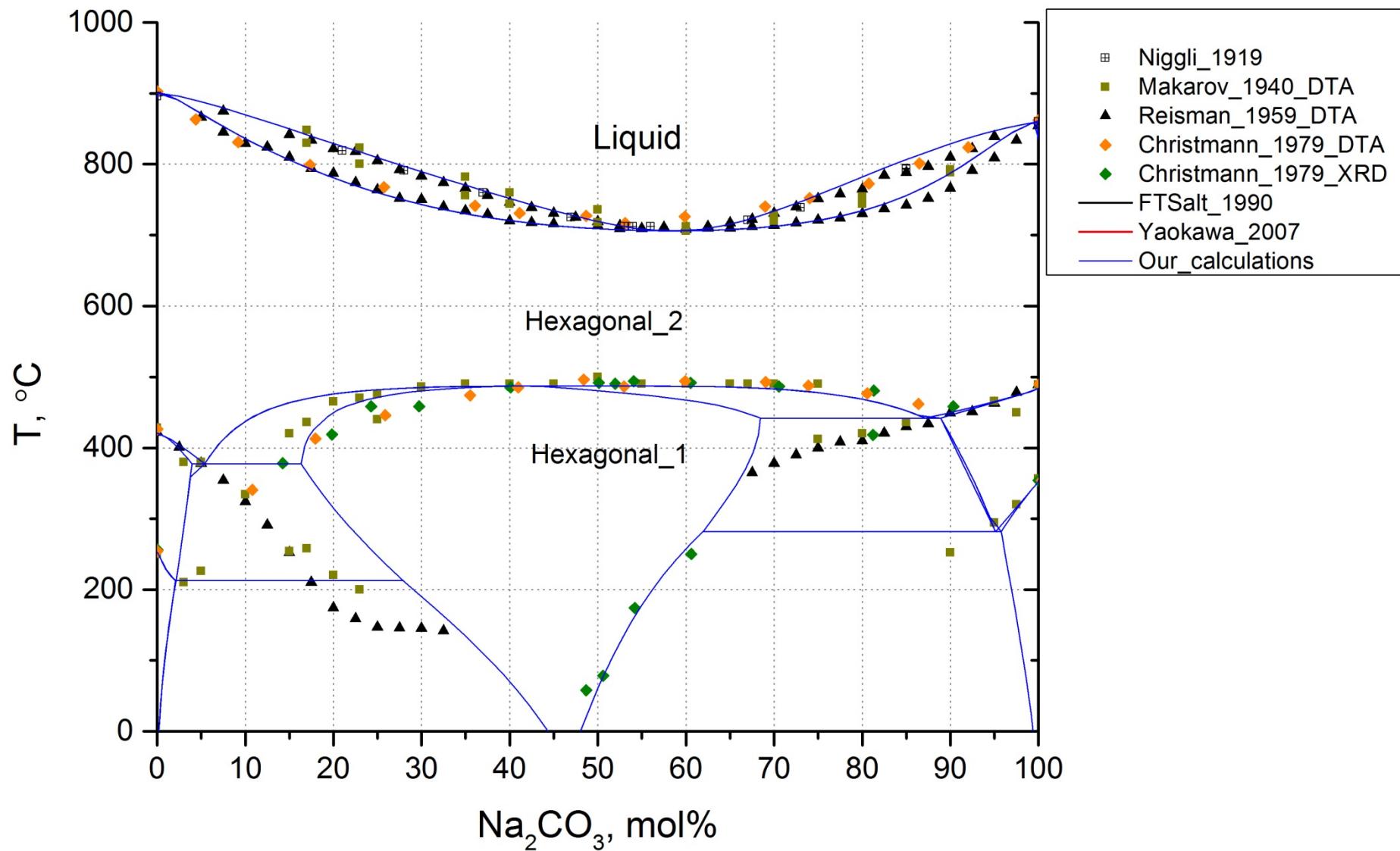
DD29A1: 50 Na<sub>2</sub>CO<sub>3</sub> - 50 K<sub>2</sub>CO<sub>3</sub> (650°C → 25°C, air)



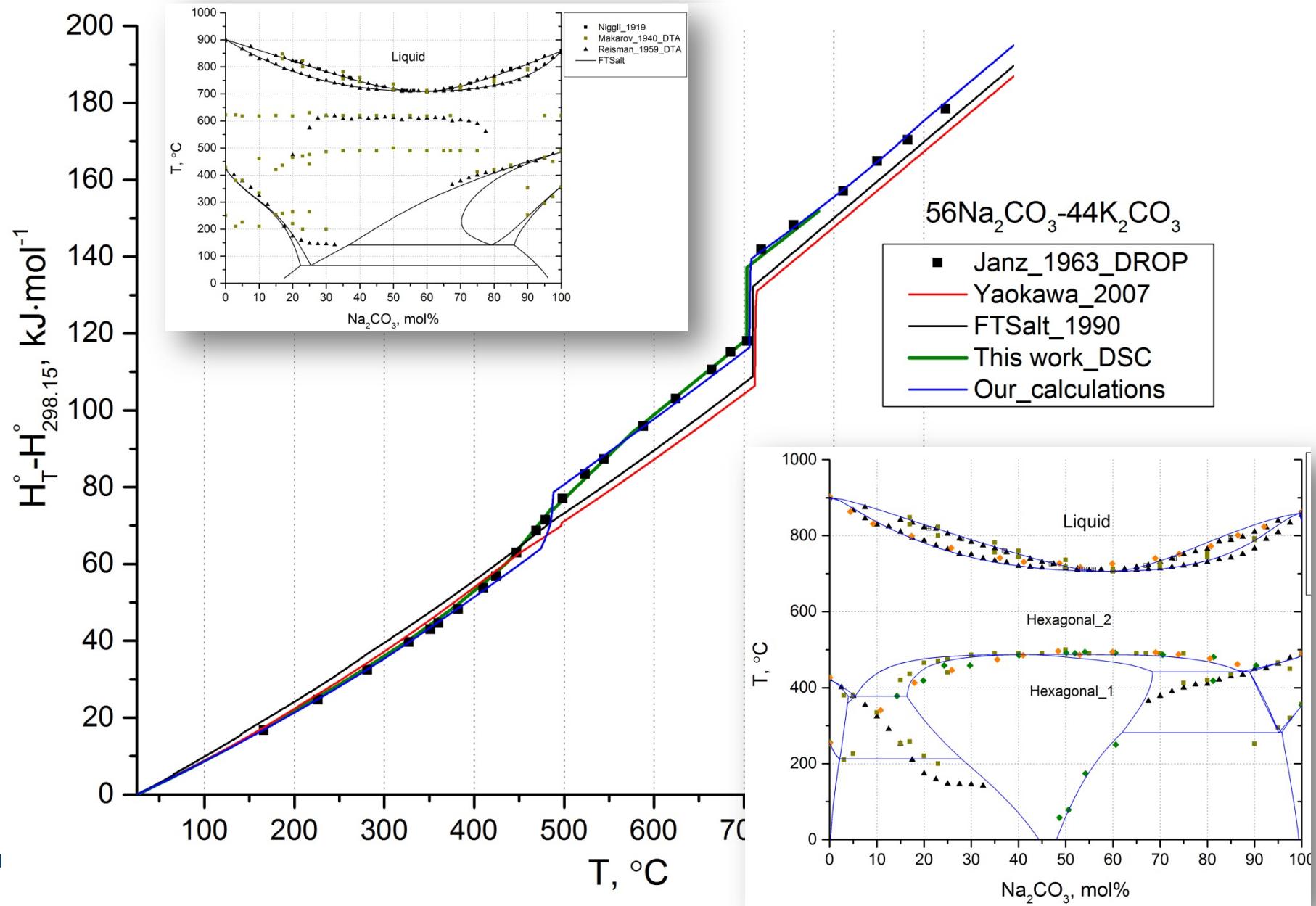
# by Increment



# $K_2CO_3$ - $Na_2CO_3$ Phase Diagram

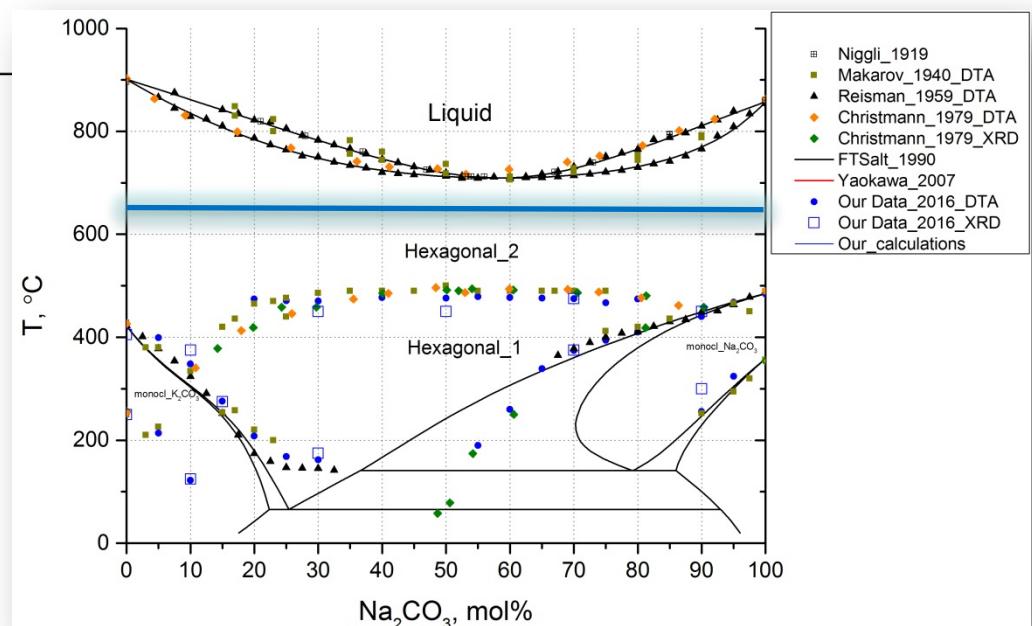
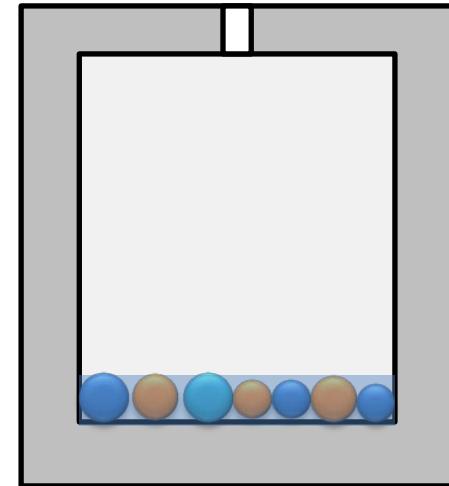
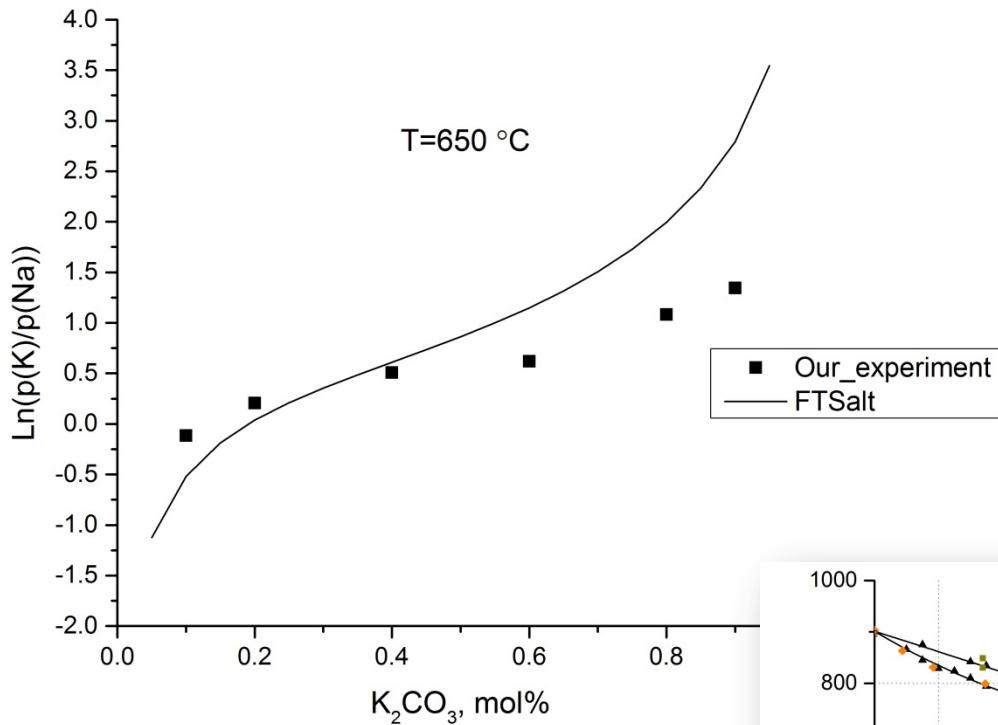


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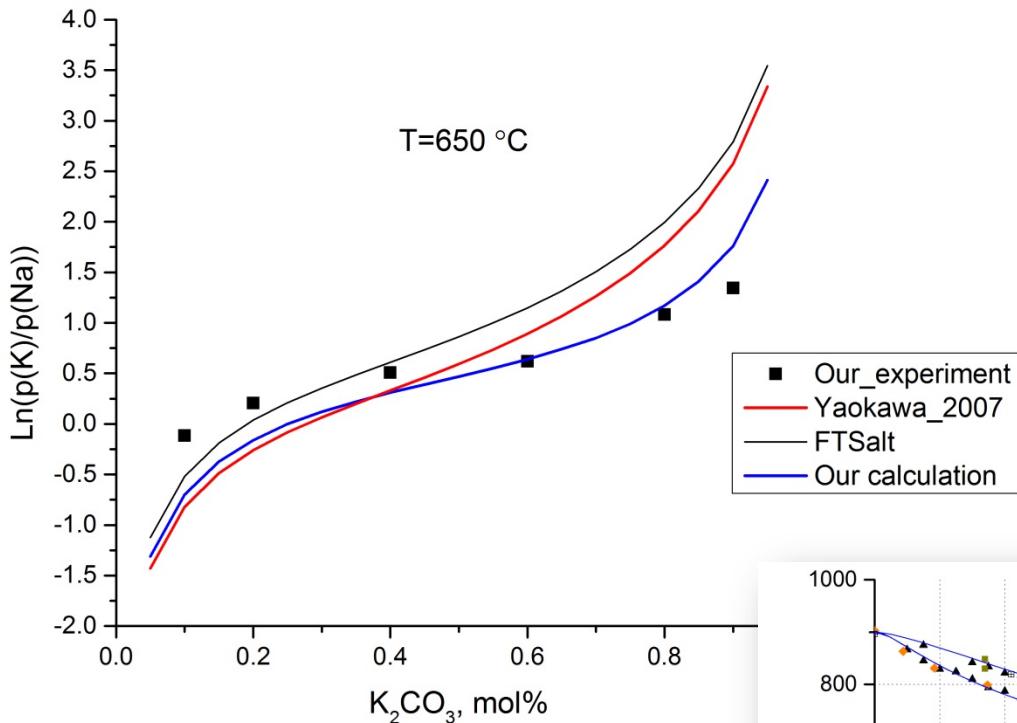


# Knudsen Effusion Mass Spectrometry

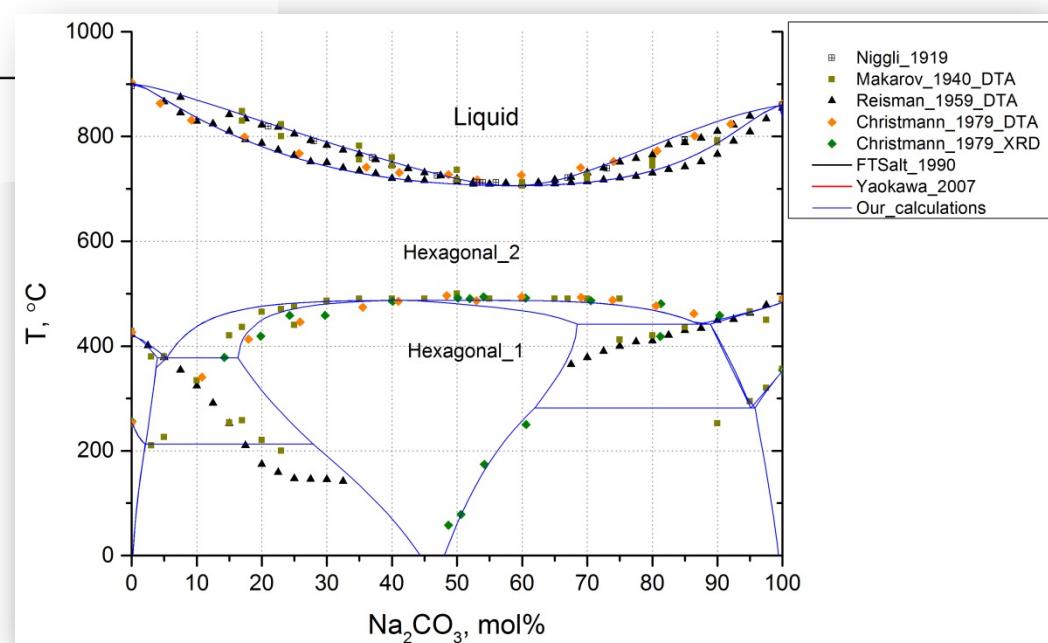
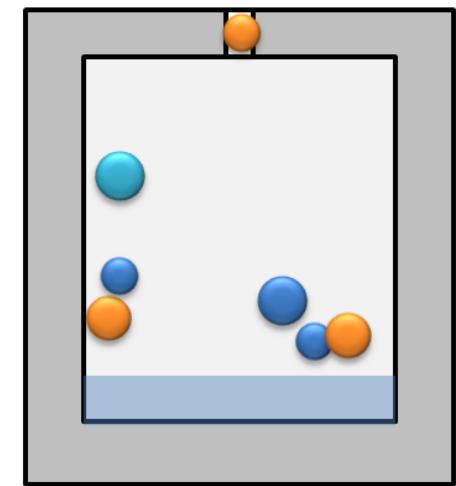
Knudsen Cell



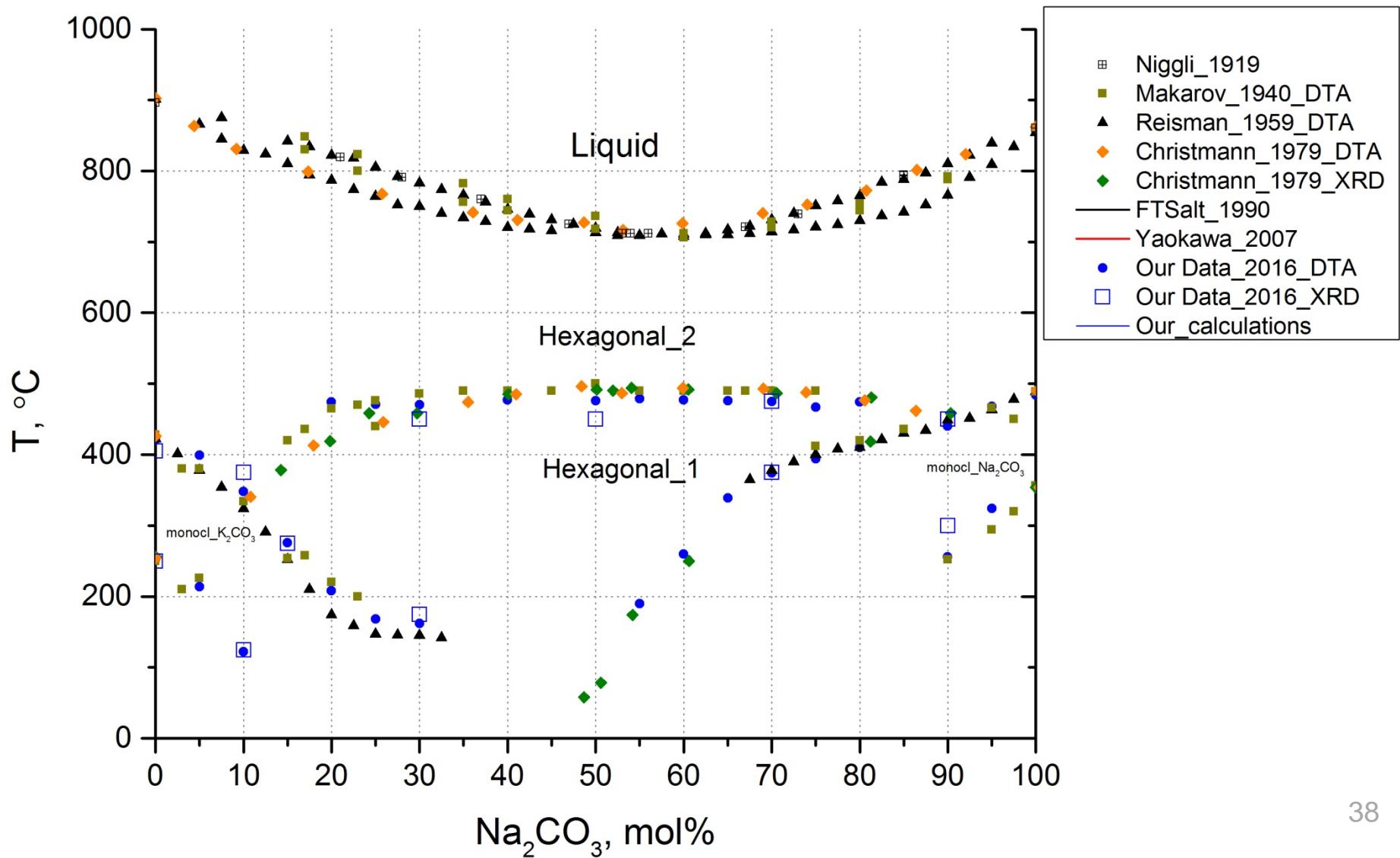
# Knudsen Effusion Mass Spectrometry



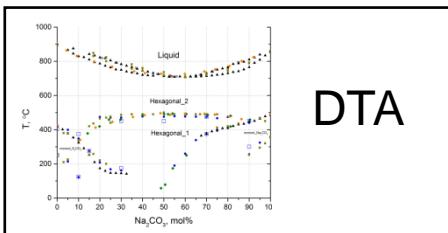
Knudsen Cell



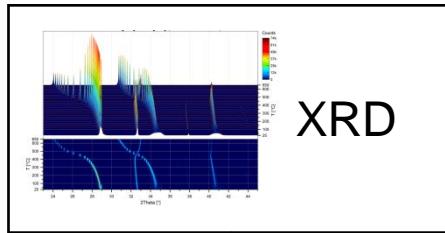
# $K_2CO_3$ - $Na_2CO_3$ Phase Diagram



# Methodology



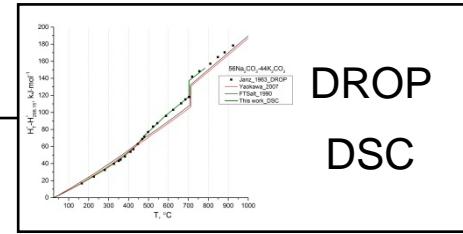
DTA



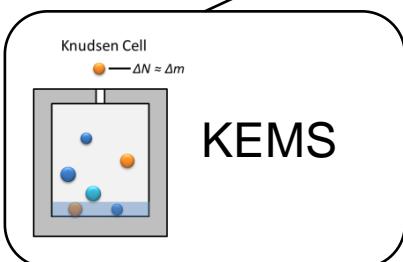
XRD



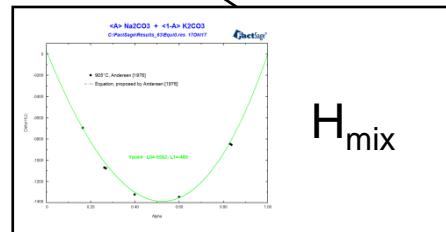
CALPHAD



DROP  
DSC

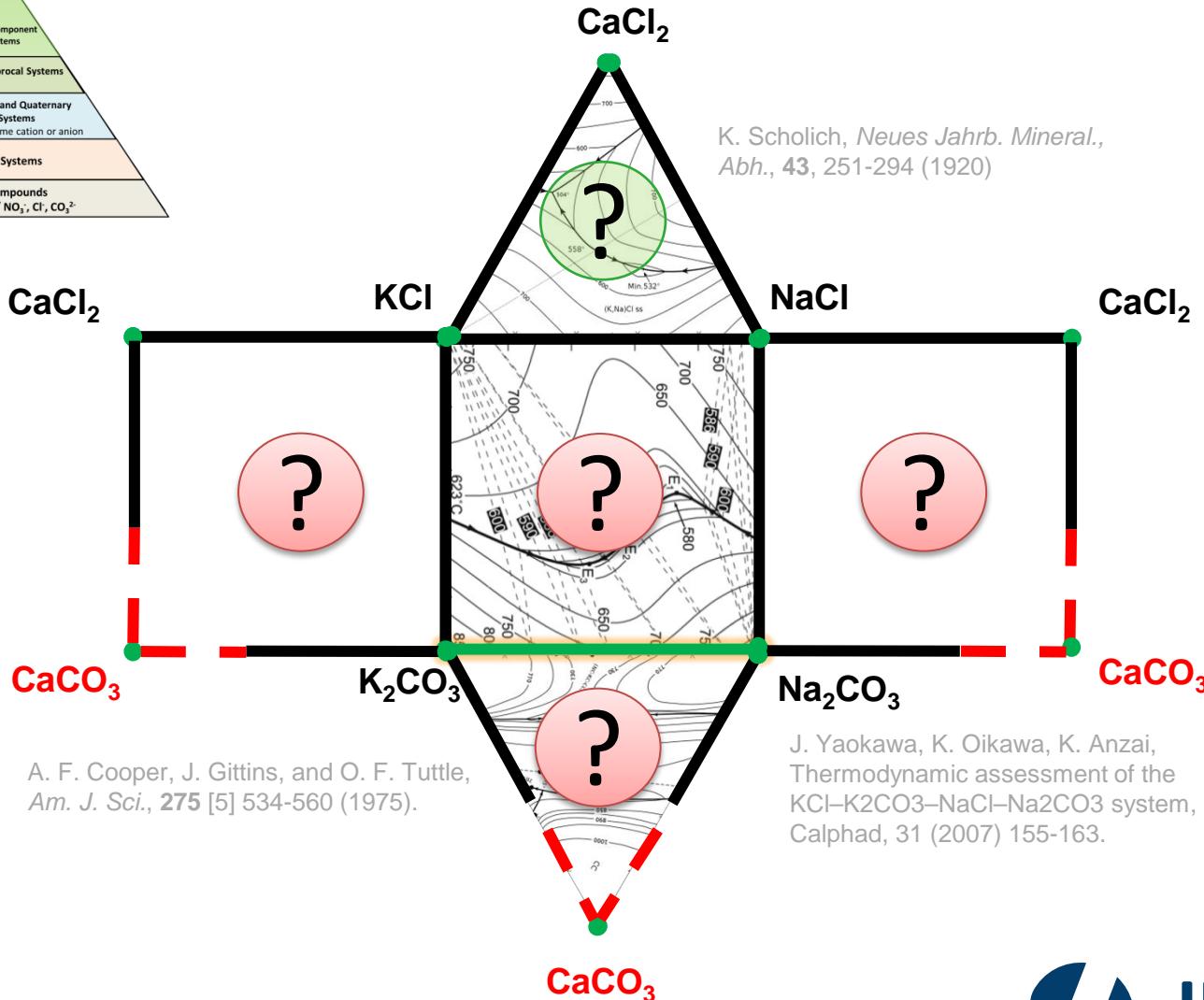
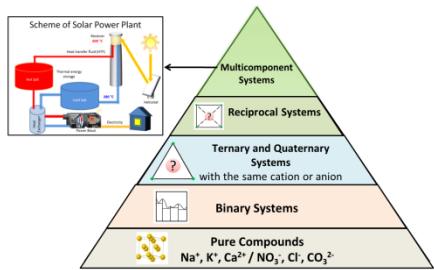


KEMS



$H_{\text{mix}}$

# Conclusions

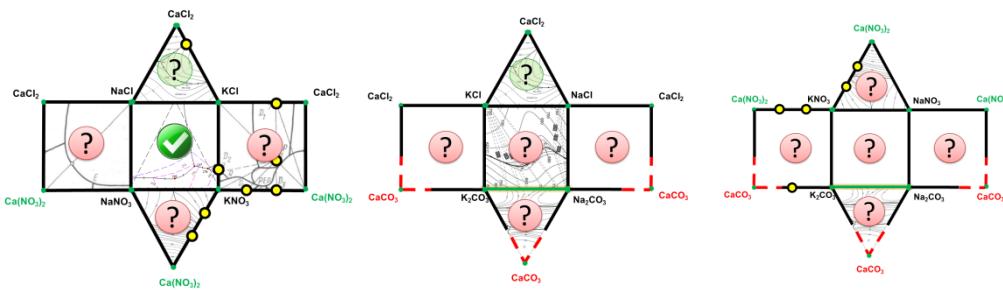


Mitglied der Helmholtz-Gemeinschaft

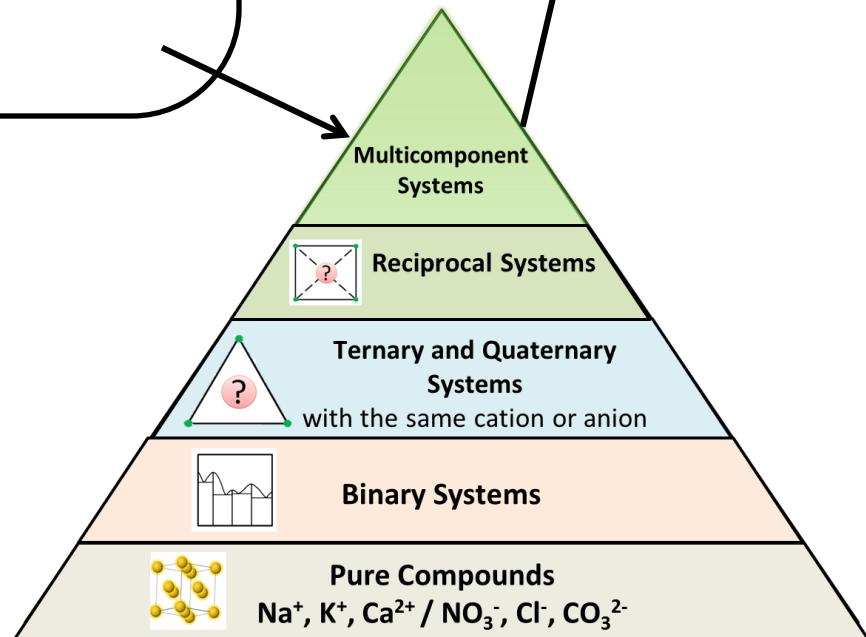
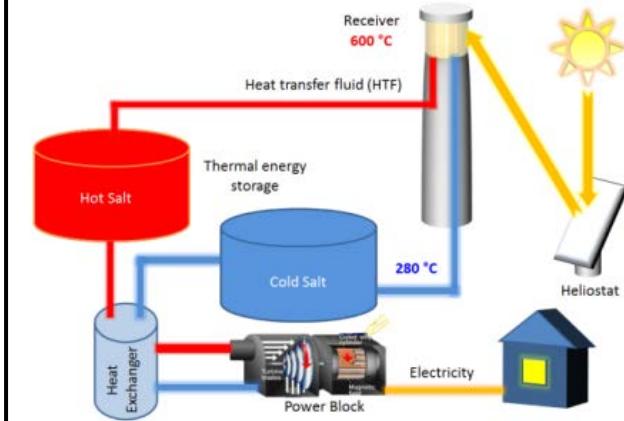
# Conclusions



## Thermodynamic Database



Scheme of Solar Power Plant



# Our Lab



Thank you for your kind attention!