### ARPES on layered compounds: From millielectron volts to femtoseconds



Kai Rossnagel

- Electronic structure movies
- Chicken and egg problem
  - Disentanglement in the time domain



Christian-Albrechts-Universität zu Kiel

# Femto-stroboscopic electronic structure movies

Graphite (around K)



 $h\nu_{probe} = 43 \text{ eV}. \ F_{abs} = 8.9 \text{ mJ/cm}^2$ 



- Momentum specific order parameter dynamics
- Nature of correlated phases
- Origin of phase transitions

### **Spectroscopic order parameters**



Charge or lattice? Chicken or egg?

## Models

### Peierls insulator: Egg before chicken



#### Peierls insulator: Egg before chicken



## Excitonic insulator: Chicken before egg



## Excitonic insulator: Chicken before egg



### Excitonic insulator: Chicken before egg



## Mott insulator: Chicken without egg



### Mott insulator: Chicken without egg



## **Time-domain classification?**

Mott insulator



Excitonic insulator



**Peierls insulator** 





### **Materials**

## **Transition-metal dichalcogenides**



Doping or (crystalline) pressure

## **17-TaS<sub>2</sub>: a Peierls-Mott insulator**



# 17-TaS<sub>2</sub>: Reconstruction + spin-orbit coupling = Mott transition



Neville Smith & KR, PRB 73, 073106 (2006)

# **1***T***-TiSe**<sub>2</sub>: an excitonic insulator?

Beamline 7, ALS, Berkeley



 $|2 \times 2 \times 2|$ 

 $h\nu = 119 \text{ eV}. T = 40 \text{ K}$ 

 $T_{ccdw} = 202 \text{ K}$ 

# Order parameter quenching



All that is solid melts into air. The Communist Manifesto

Nature 471, 490 (2011)

## trARPES using HHG: 17-TiSe<sub>2</sub>



# Snapshots (17-TiSe<sub>2</sub>)



s-polarized probe  $F_{abs} = 5 \text{ mJ/cm}^2$ 

### **Order parameter transients (17-TiSe<sub>2</sub>)**



### **Build-up of screening (17-TiSe<sub>2</sub>)**



see also Petersen et al., PRL 107, 177402 (2011)

## **Reference system: 1***T***-TaS<sub>2</sub>**



# **Hierarchy of quenching times**



### Conclusions

# Real charge-density waves: Chicken and egg simultaneously



## **Time-domain classification**

Mott insulator







**Peierls insulator** 







### **Recent experimental progress**





## Thanks to ...



S. Hellmann C. Sohrt K. Hanff M. Kalläne L. Kipp

T. Rohwer M. Wiesenmayer A. Stange B. Slomski M. Bauer S. Eich S. Mathias M. Aeschlimann

Y. Liu L. Miaja Avila S. Mathias M. Murnane H. Kapteyn

A.Carr

A. Bostwick E. Rotenberg





bmb+f

Großgeräte der physikalischen Grundlagenforschung