

Possible light-induced superconductivity in K_3C_{60} at high temperature

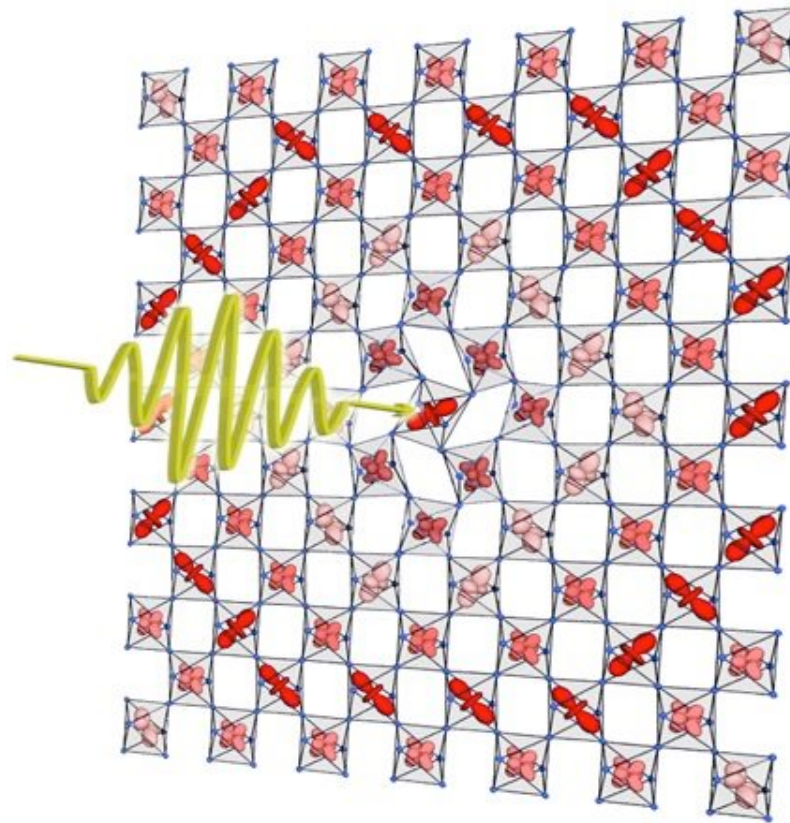
Matteo Mitrano

Max Planck Institute for the Structure and Dynamics of Matter,
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Urbana, USA

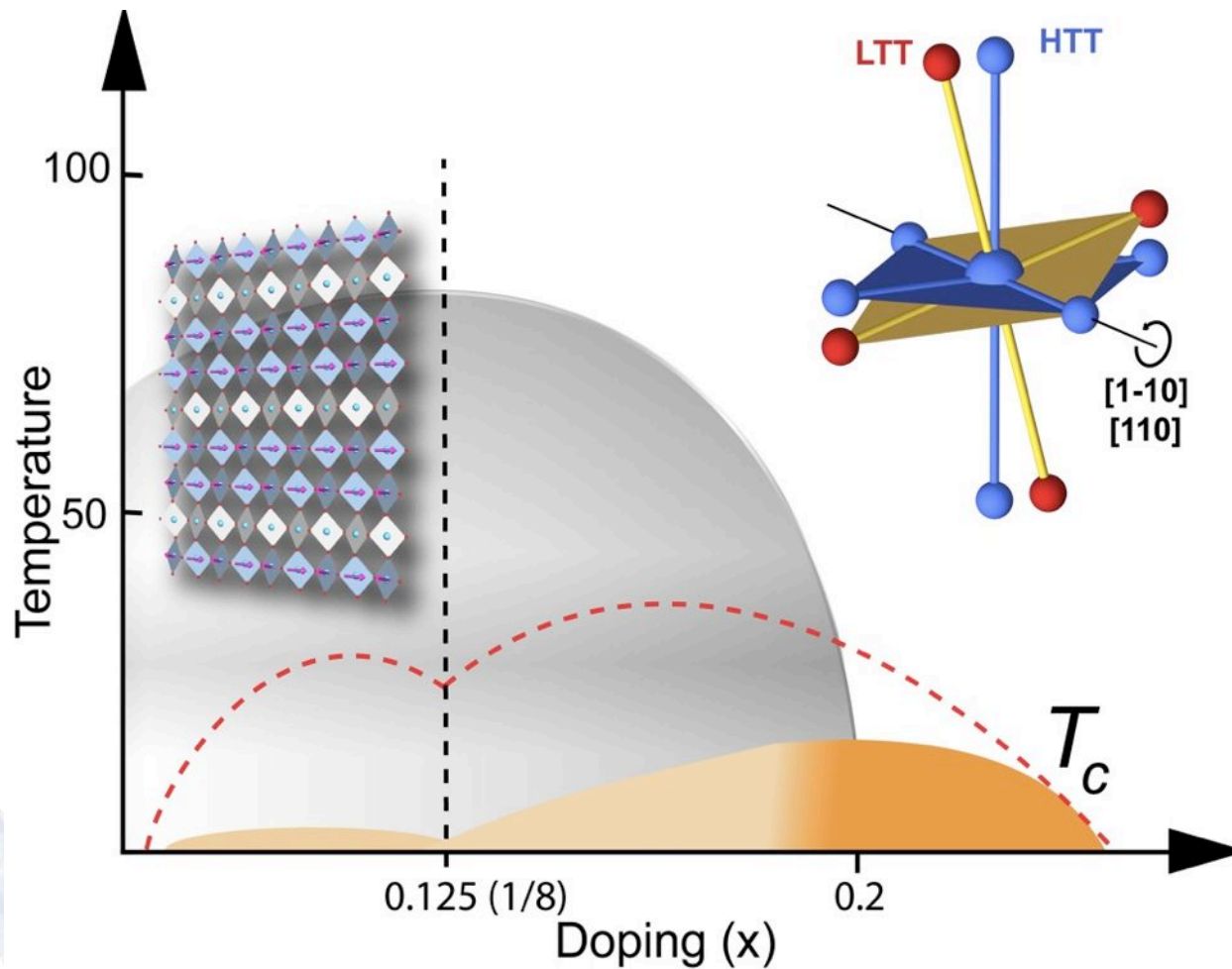
7th International NGSCES Conference
Trieste, Italy – 09.26.2016

Resonant excitation of the lattice



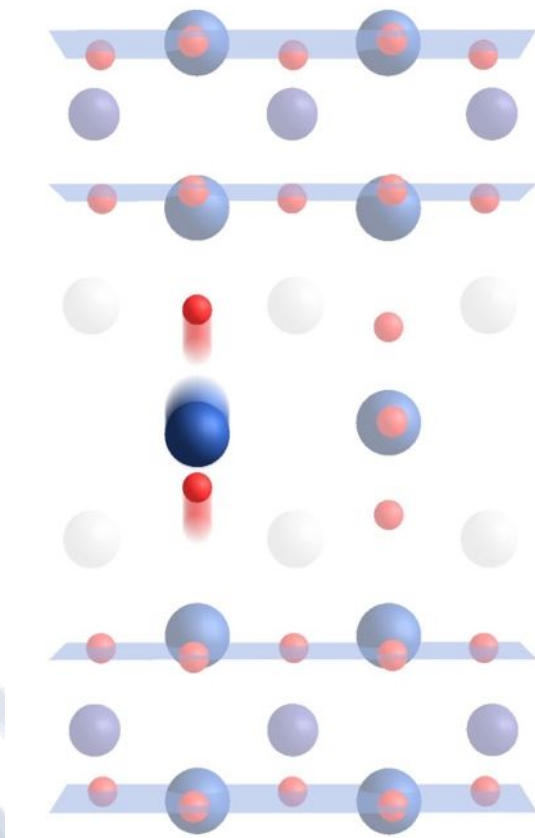
Vibrational excitation of strongly correlated system

Light-induced superconductivity

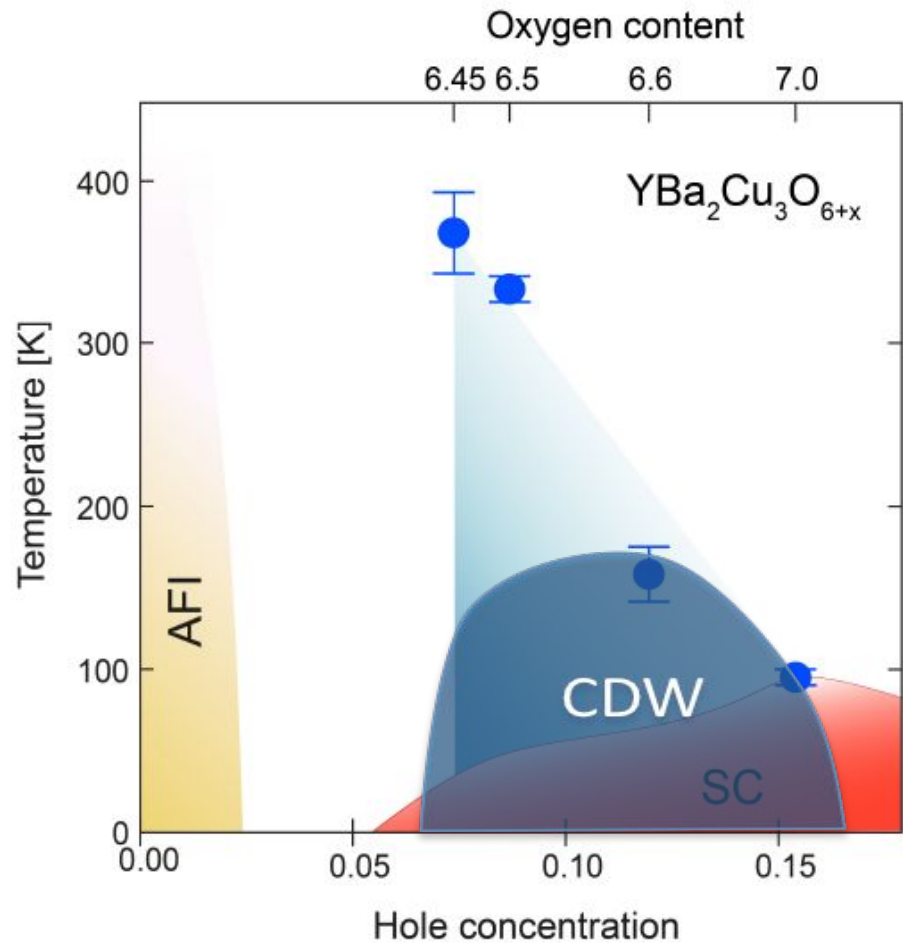


D. Fausti et al., Science 331, 6014 (2011)

Light-enhanced superconductivity



Mankowsky et al.
***Nature* 516, 71 (2014)**

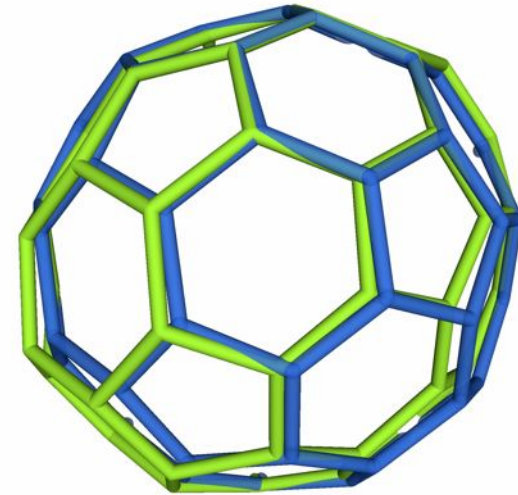
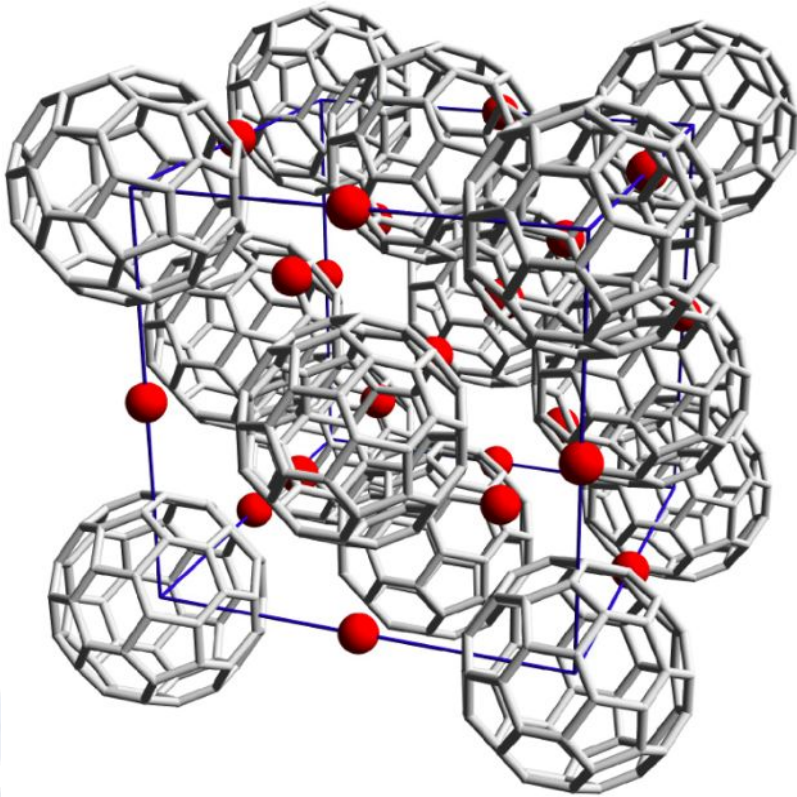


W. Hu et al., *Nature Materials* 13, 705 (2014)
S. Kaiser et al., *PRB* 89, 184616 (2014)

Is the underlying physics specific to the cuprates ?

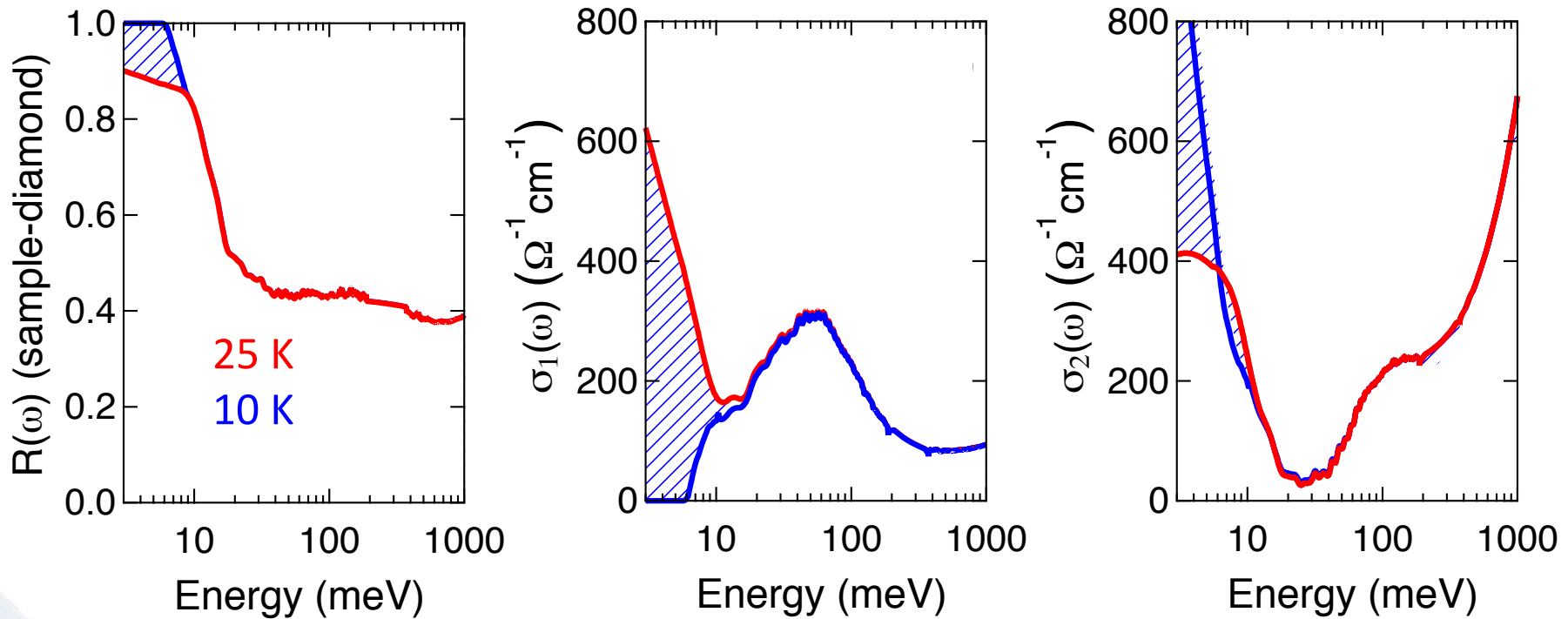
**What would happen in phonon-mediated
superconductors?**

The K_3C_{60} superconductor



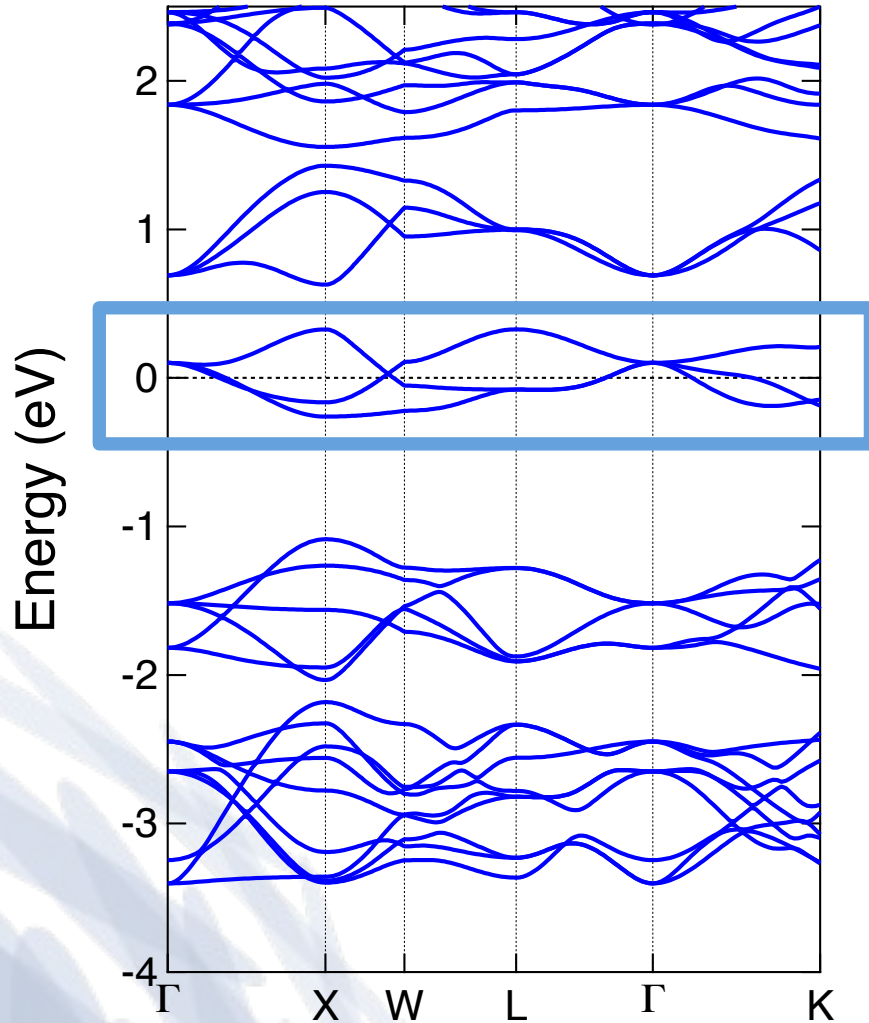
- Organic molecular solid
- High T_c (20 K)
- 3D electronic structure

Equilibrium superconductivity in K_3C_{60} m-psd



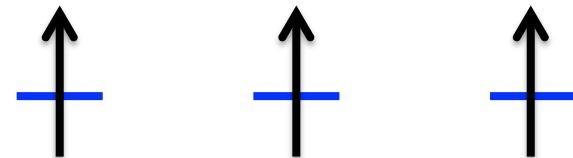
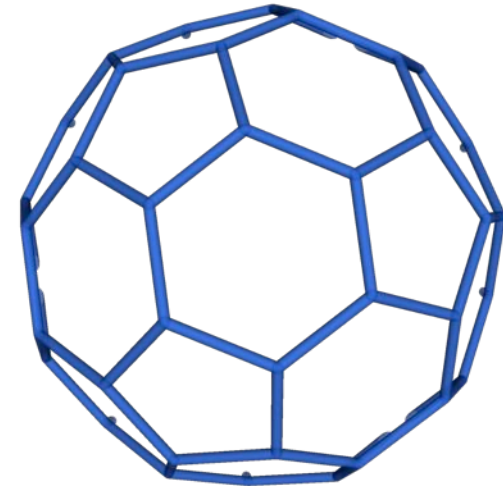
- $R=1$ below gap
- Gap opening in $\sigma_1(\omega)$
- Increase in $\sigma_2(\omega)$

Pairing interaction in K_3C_{60}

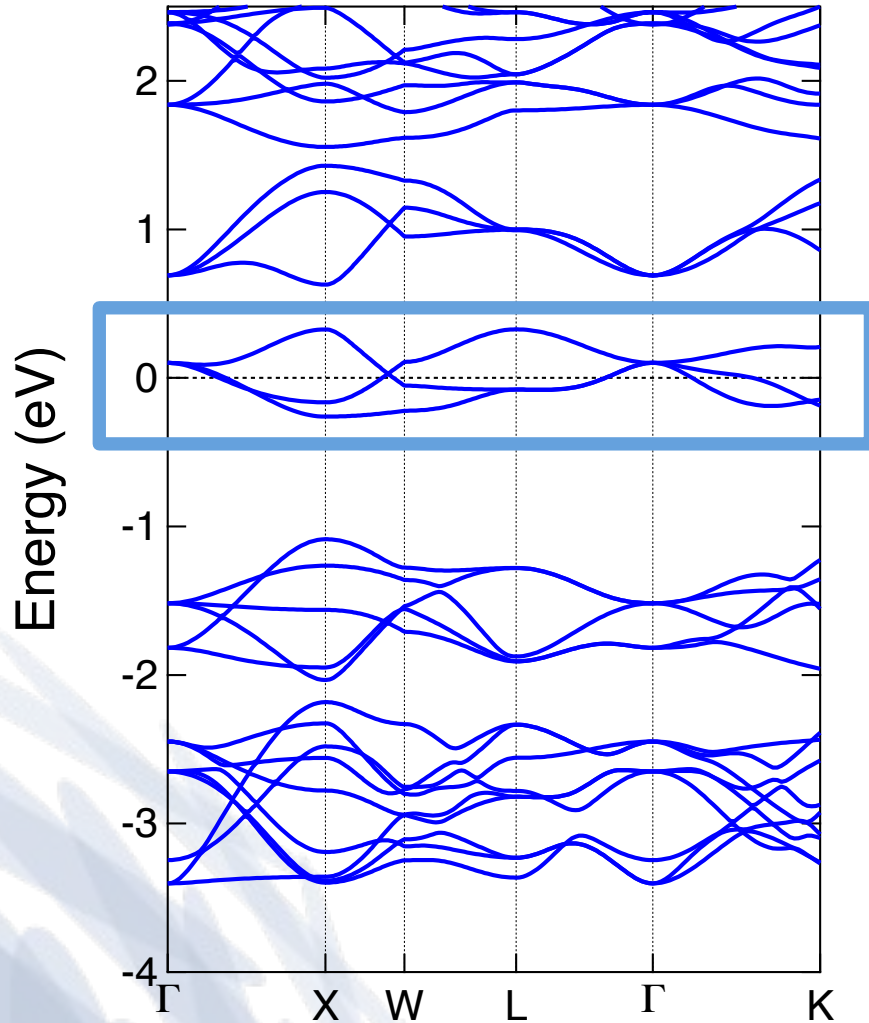


Courtesy of A. Subedi

t_{1u}
Narrow
bandwidth
0.5 eV

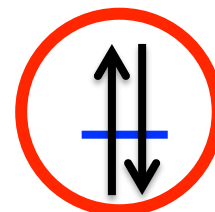
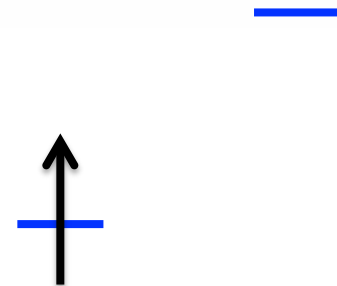
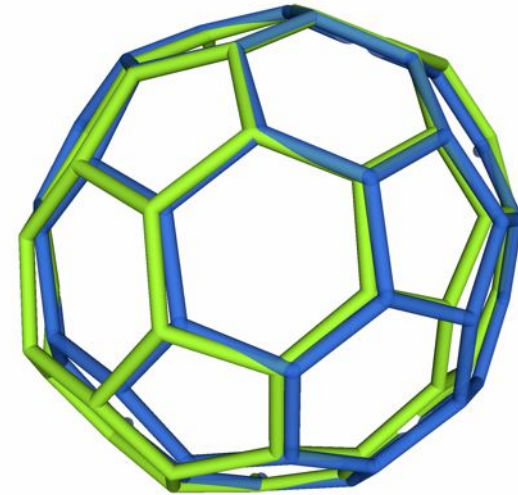


Pairing interaction in K_3C_{60}

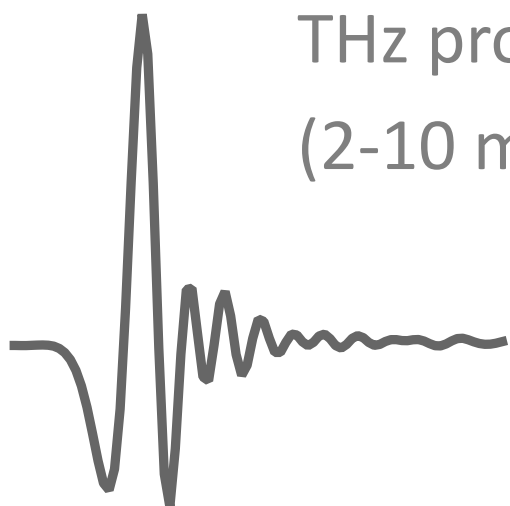


Courtesy of A. Subedi

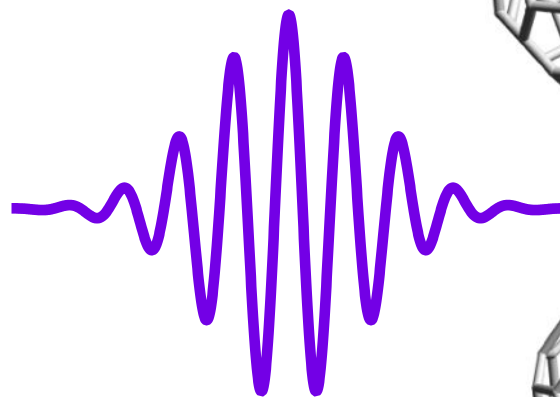
t_{1u}
Narrow
bandwidth
0.5 eV



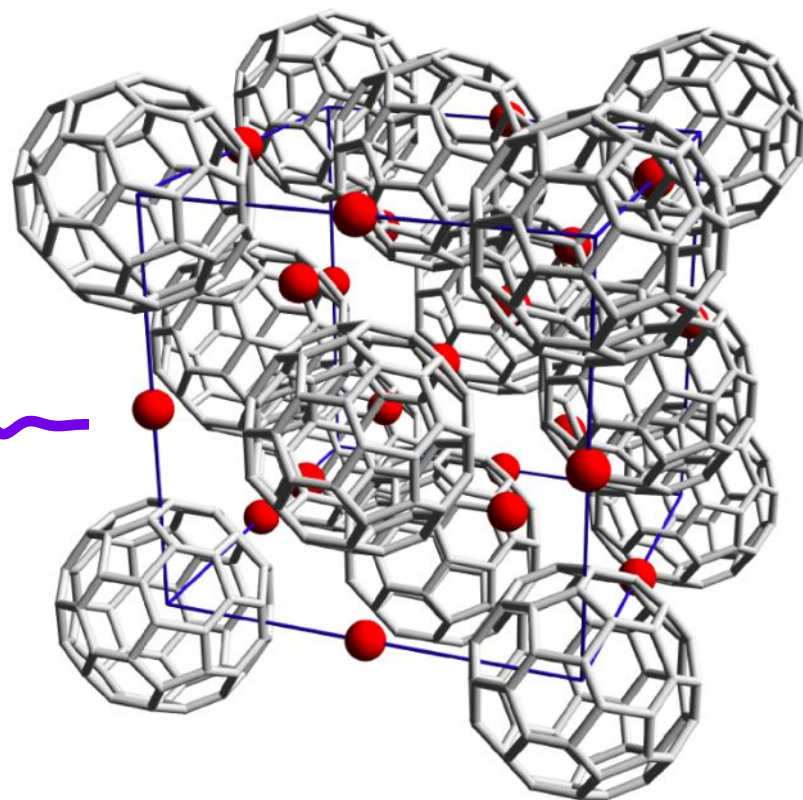
Exciting the C_{60} molecular modes



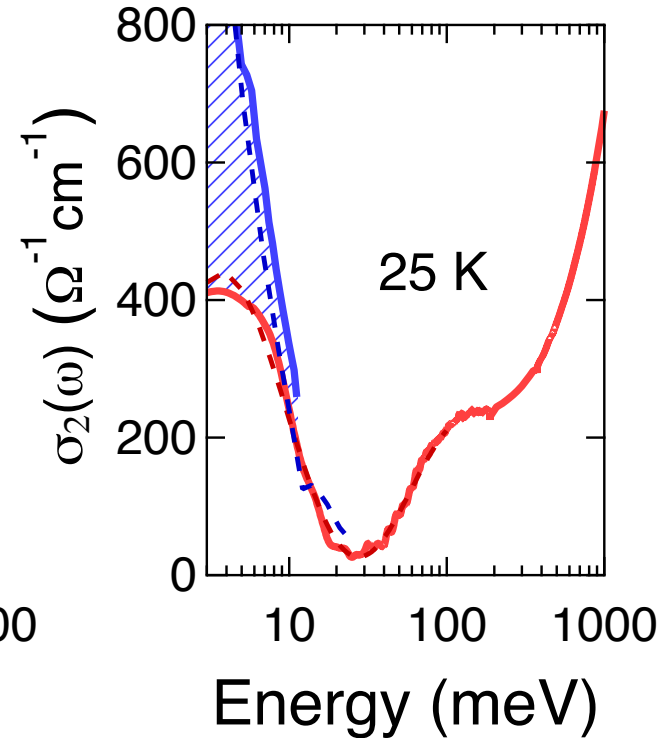
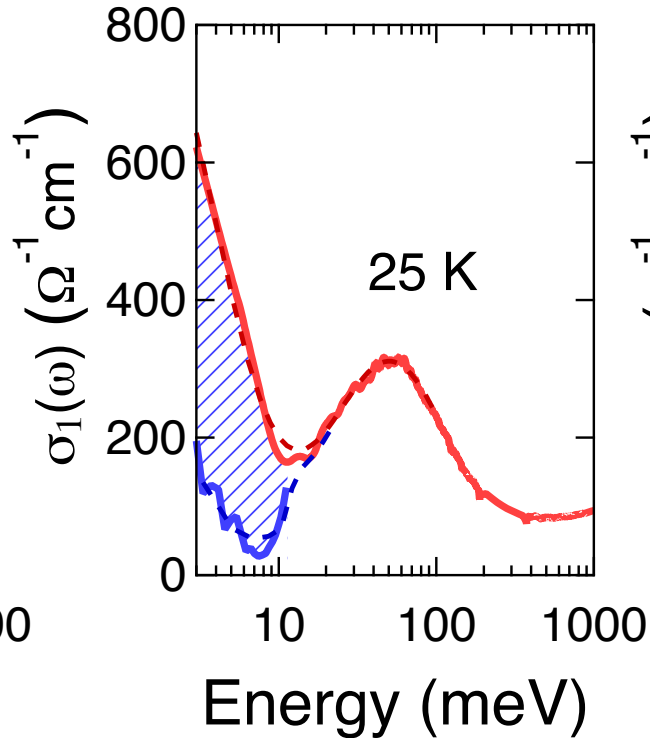
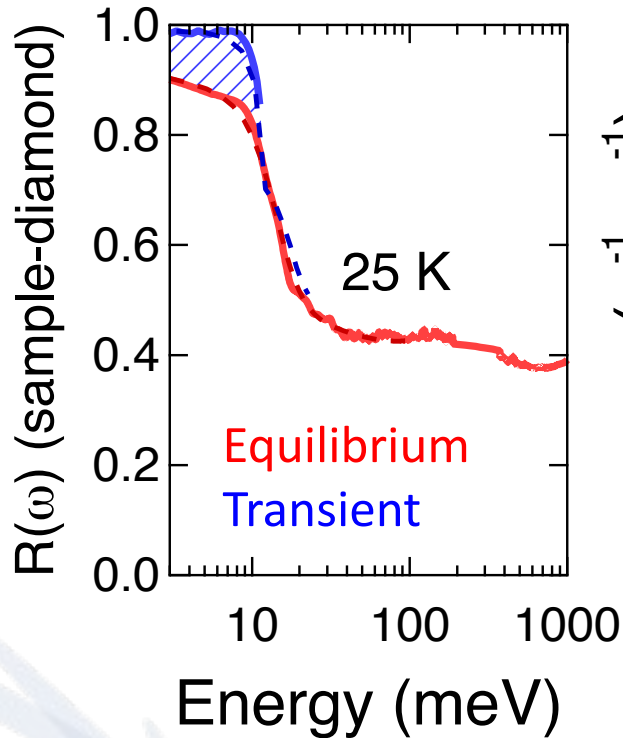
THz probe
(2-10 meV)



MIR pump
170 meV

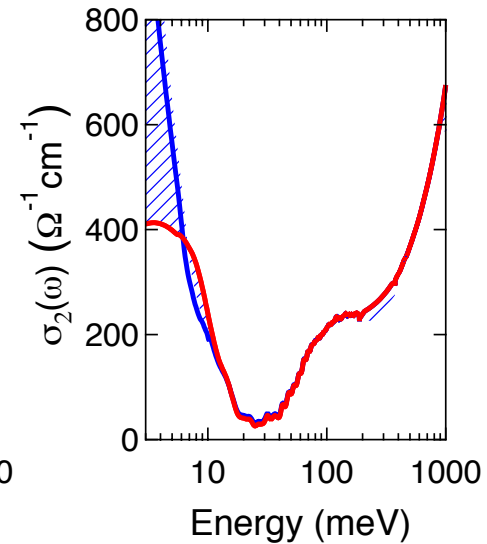
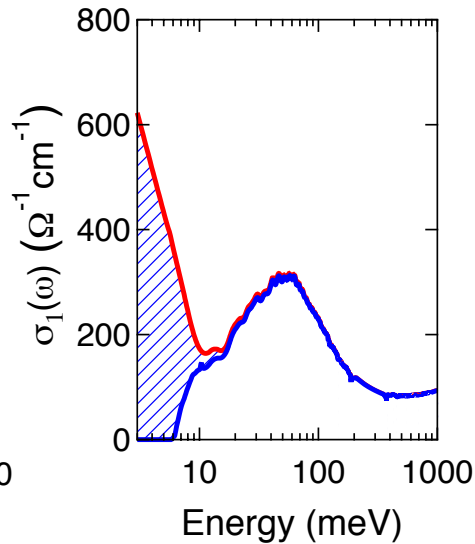
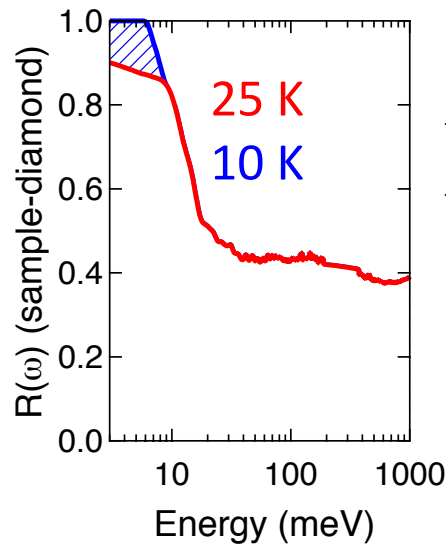


Transient superconducting-like phase

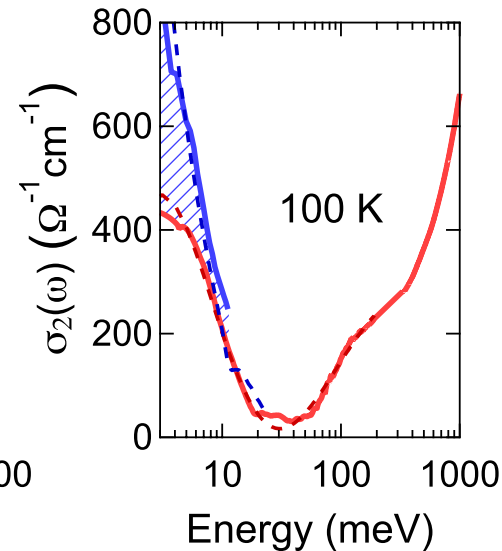
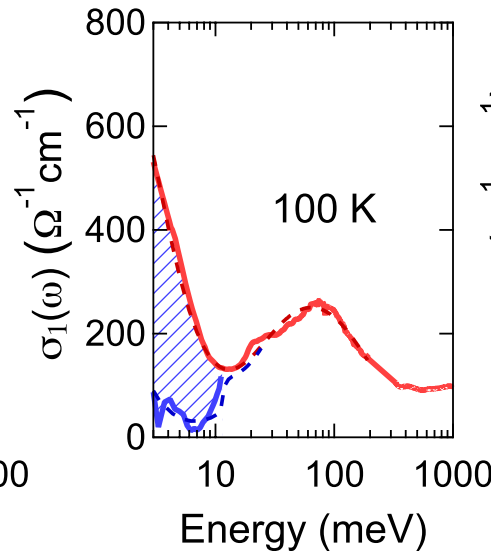
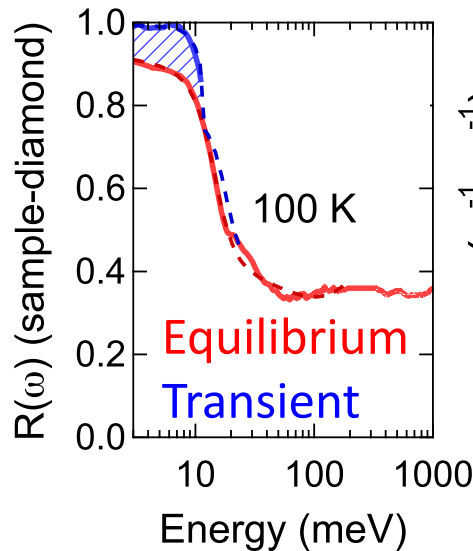


- Increase in $R(\omega)$
- Gap opening in $\sigma_1(\omega)$
- Increase in $\sigma_2(\omega)$

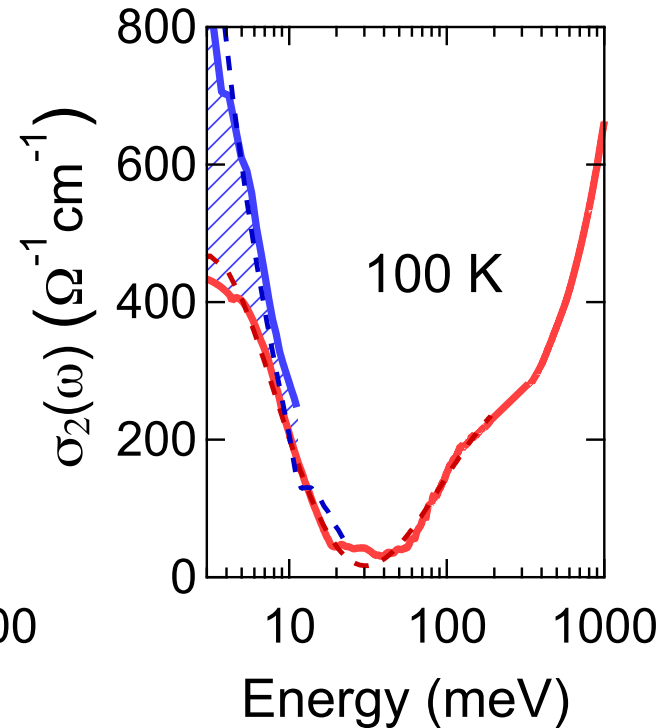
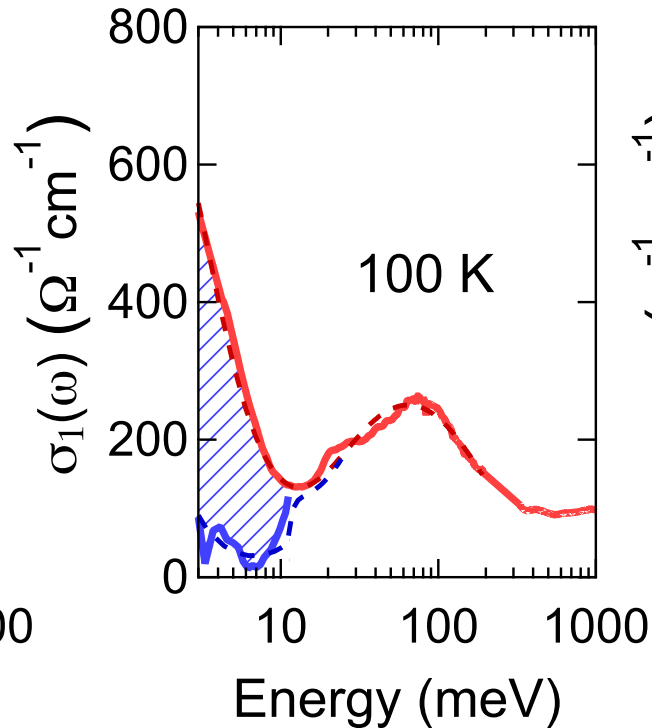
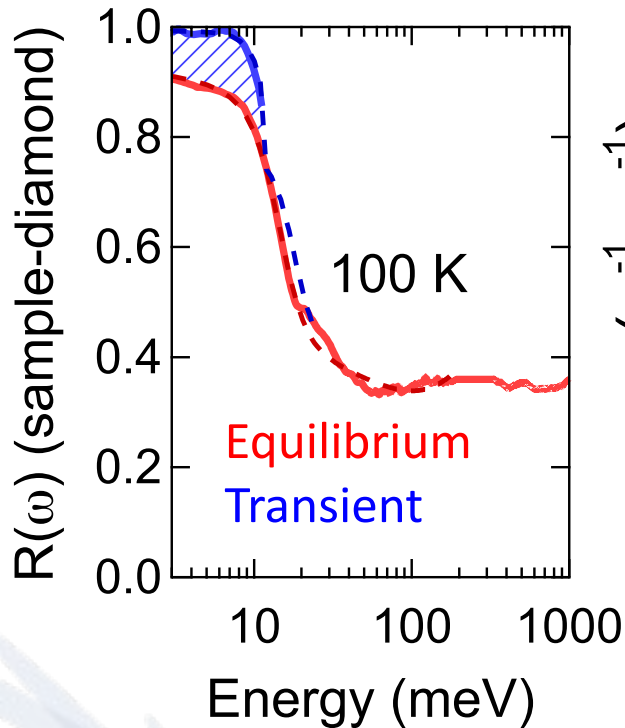
Temperature driven



Light driven

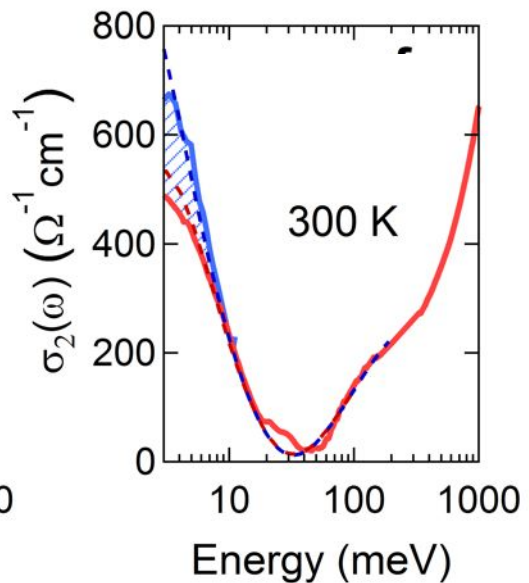
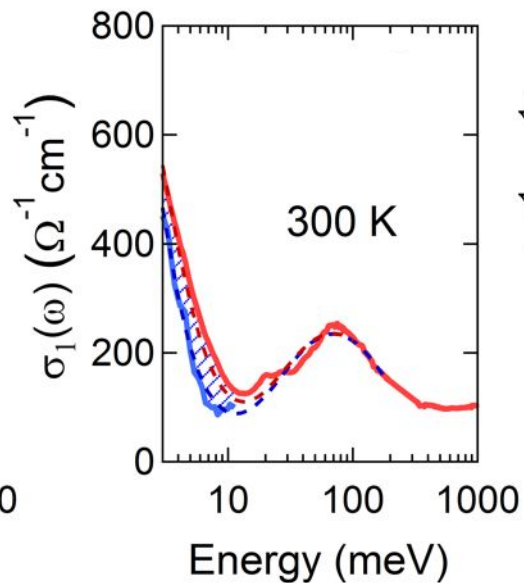
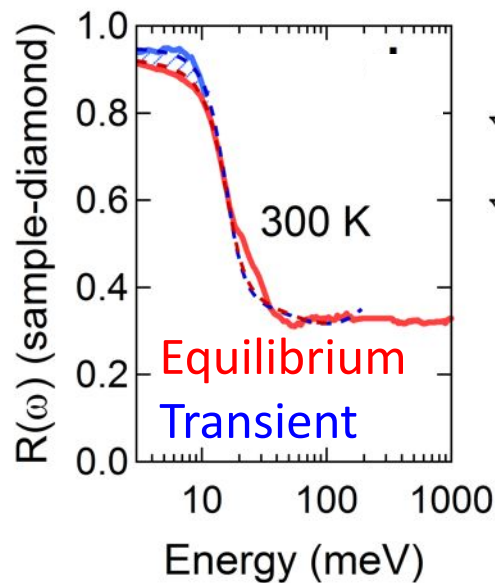
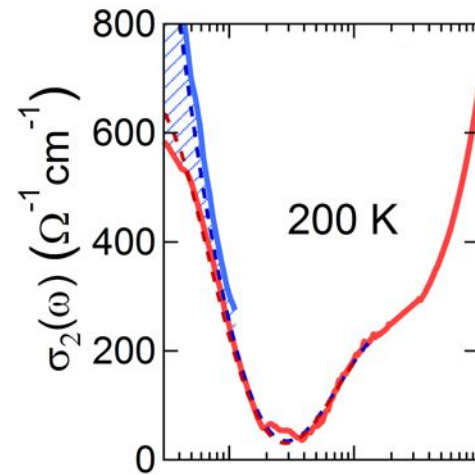
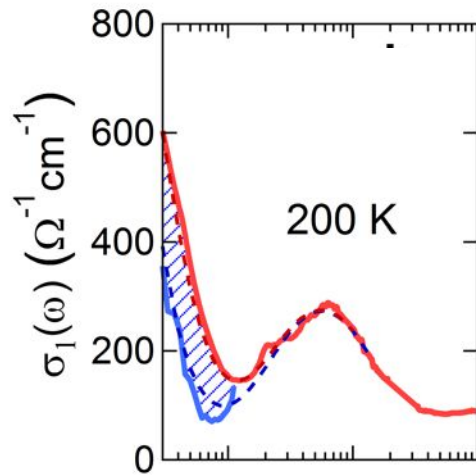
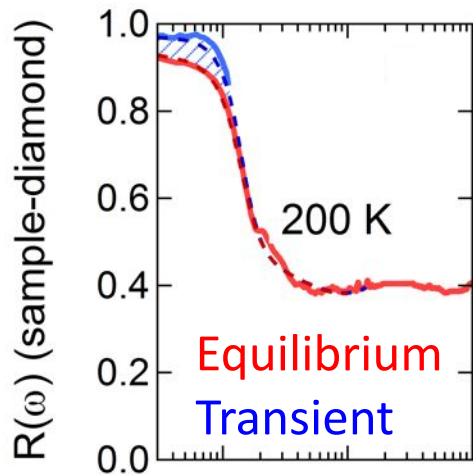


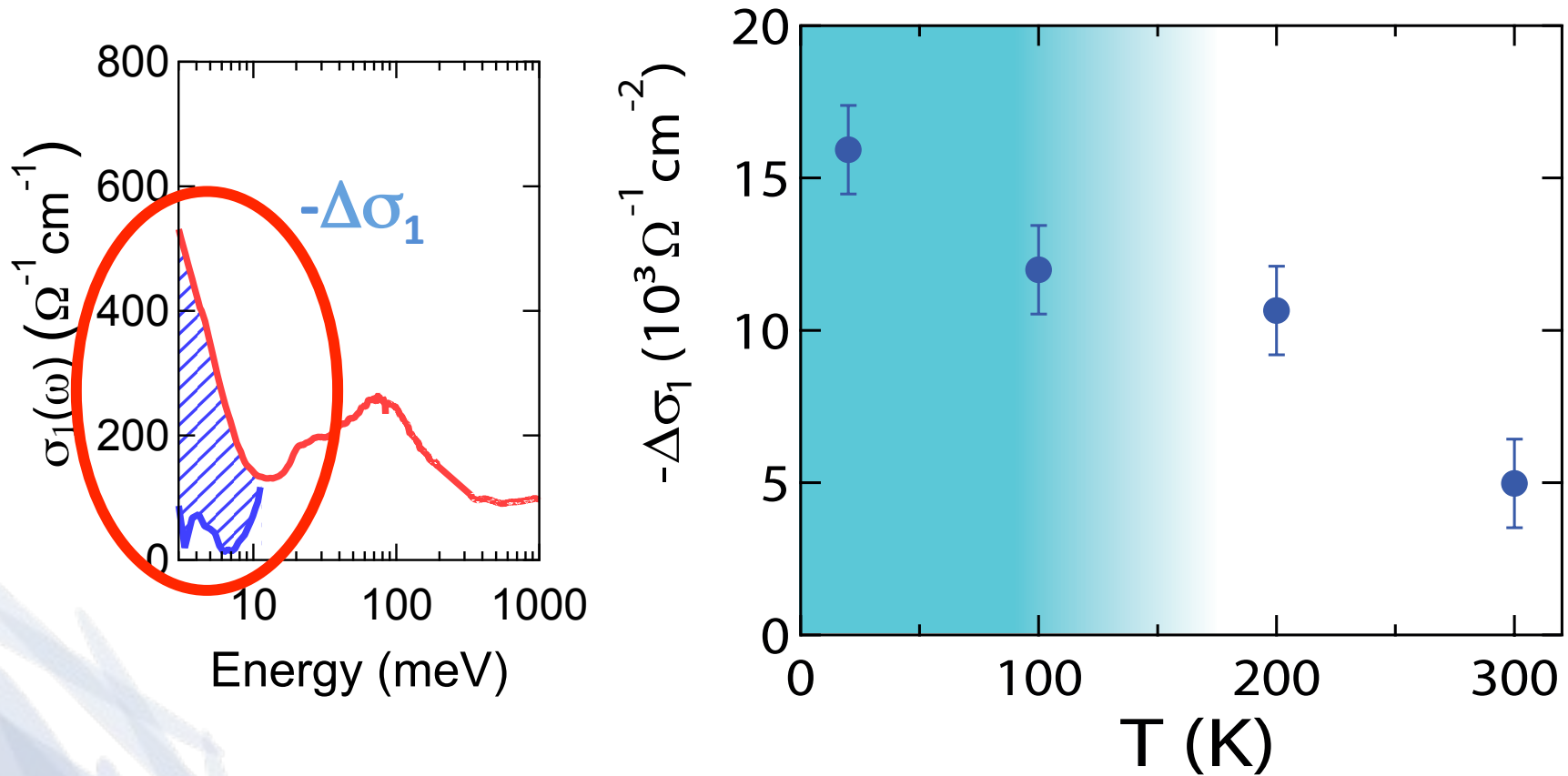
Light-induced state far above T_c



- Increase in $R(\omega)$
- Gap opening in $\sigma_1(\omega)$
- Increase in $\sigma_2(\omega)$

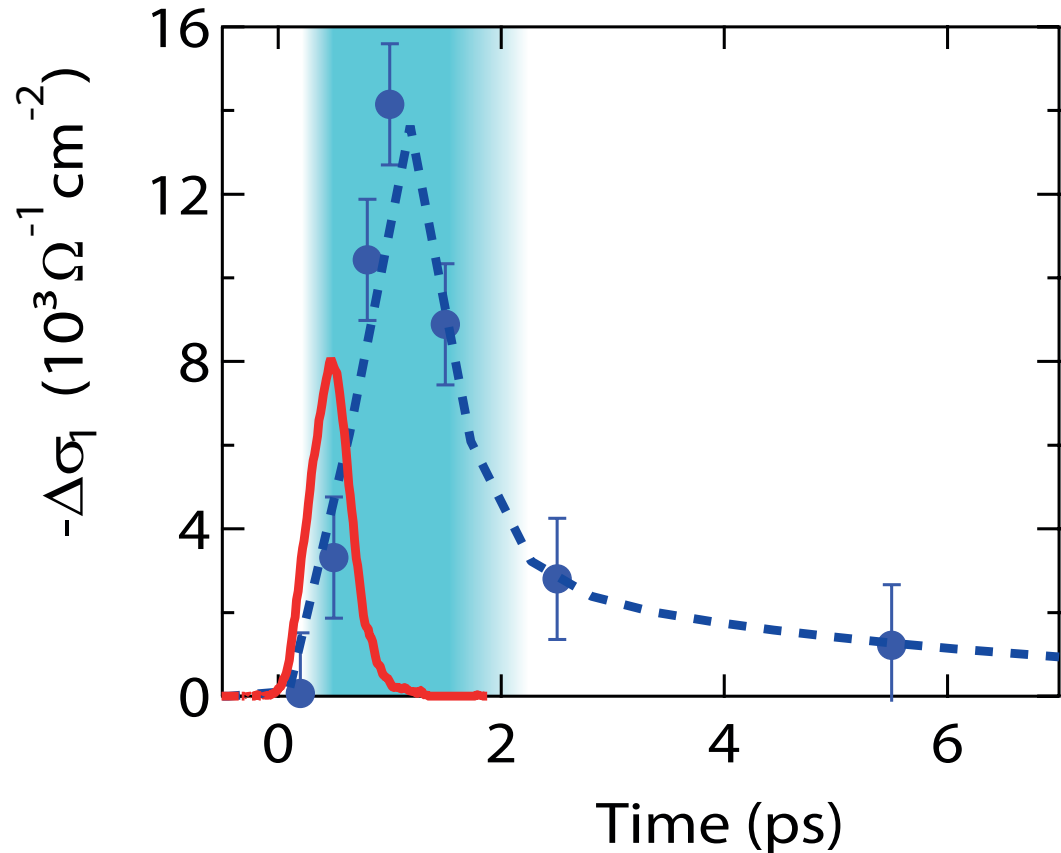
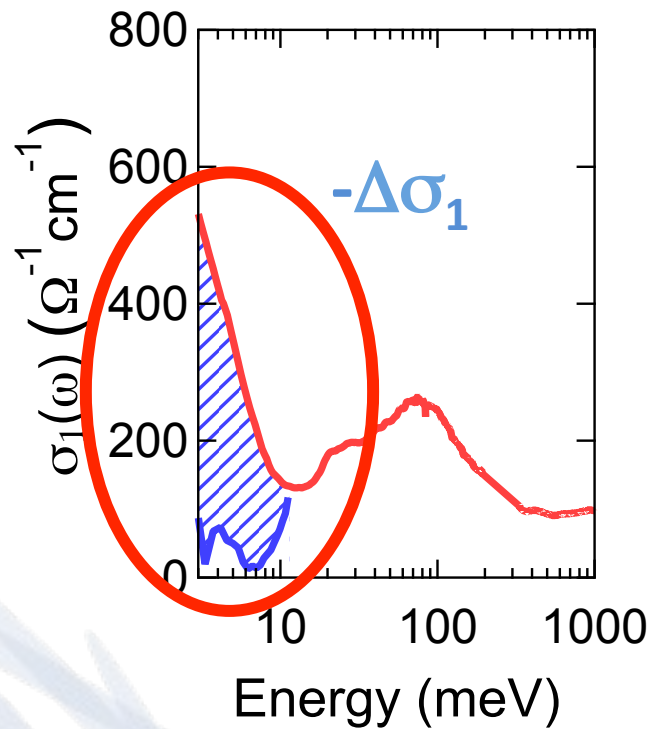
Gap closure at high temperature





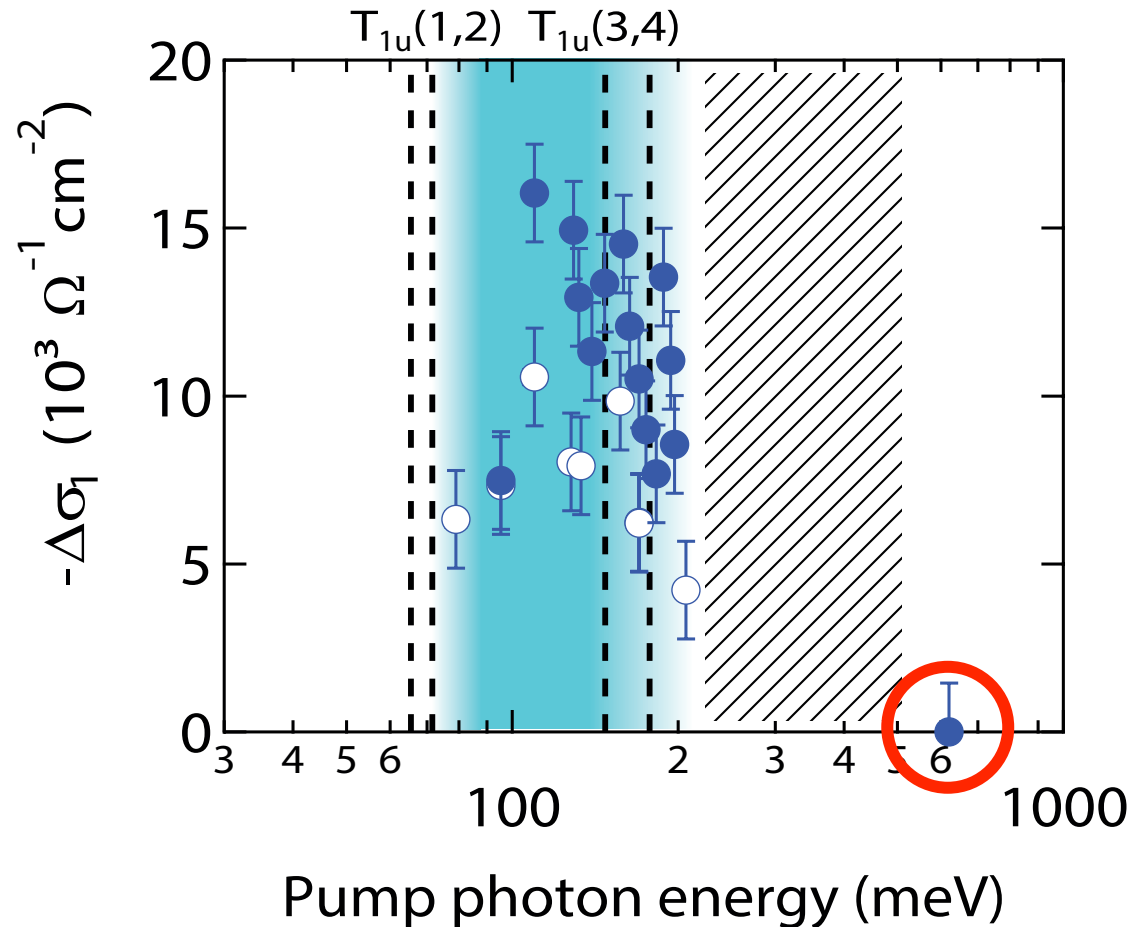
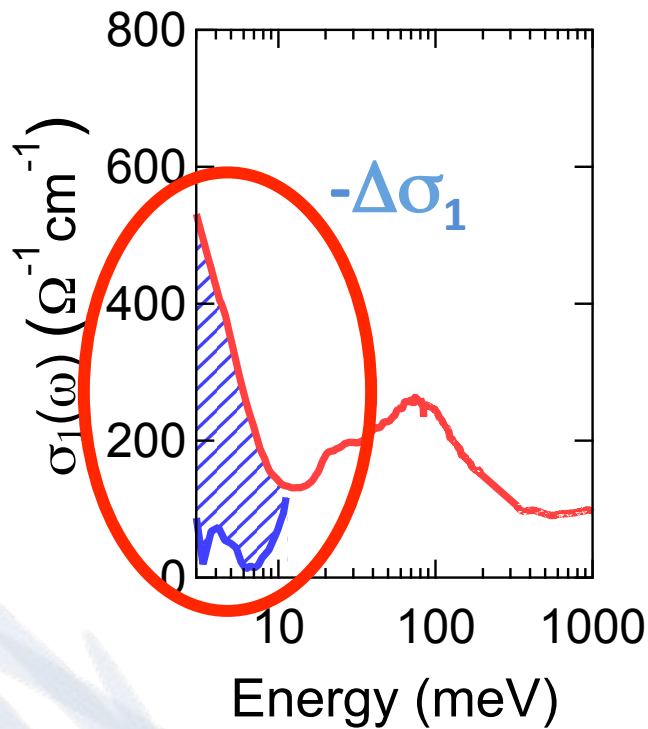
Smooth reduction of the light-induced effect

Dynamics of the light-induced state



Superconducting-like to high-mobility metal in 2 ps

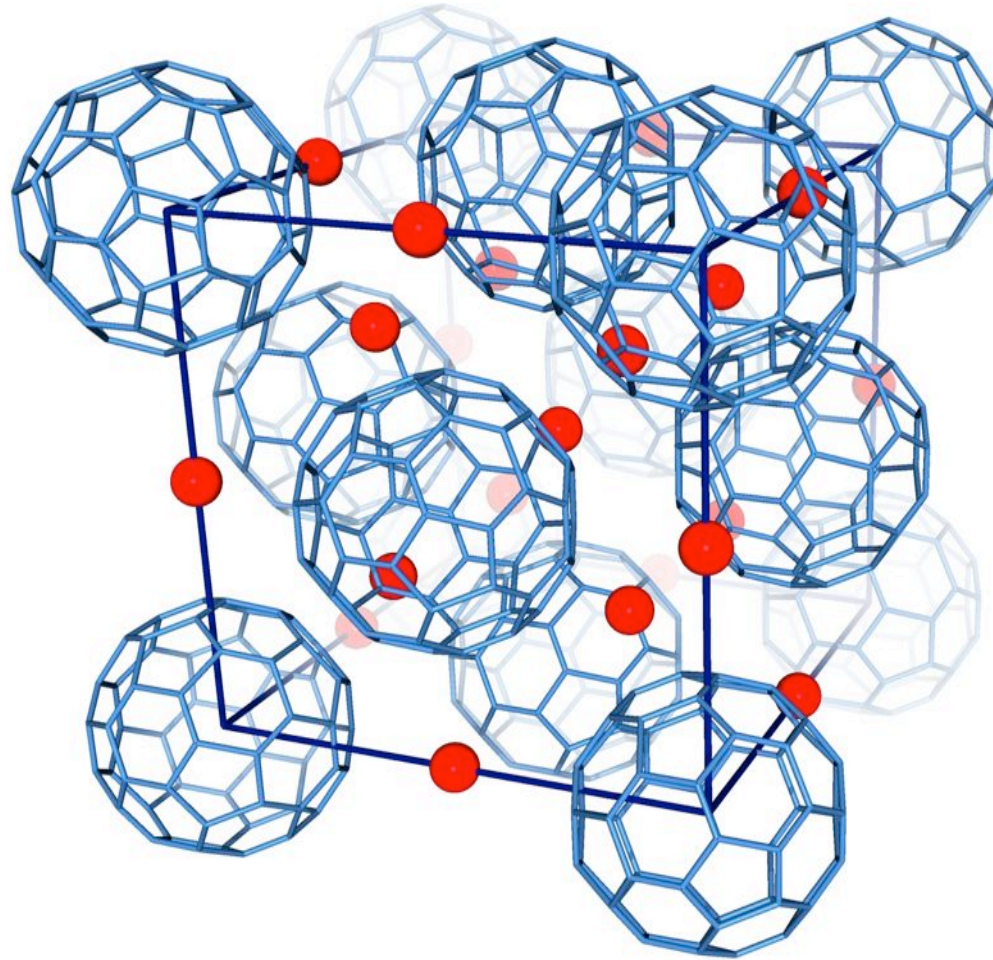
Resonant behavior of the excitation



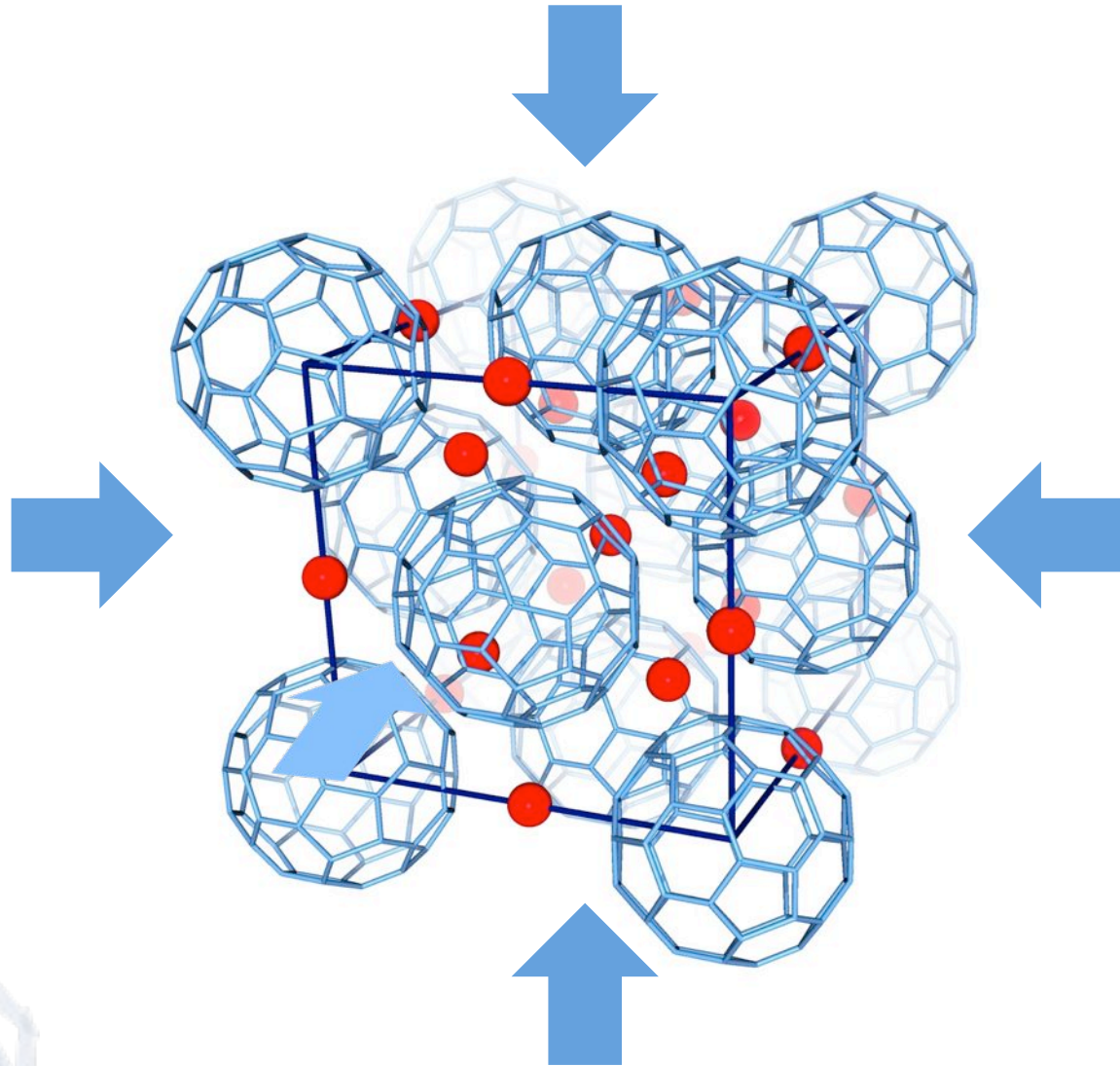
- Broad resonance between the T_{1u} modes
- No response at 600 meV

How does the transient state react to external static pressure?

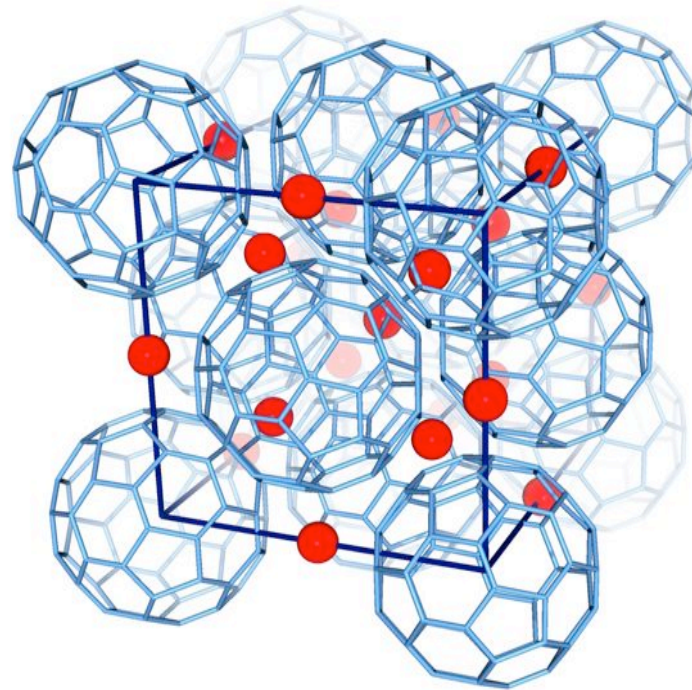
Application of external pressure



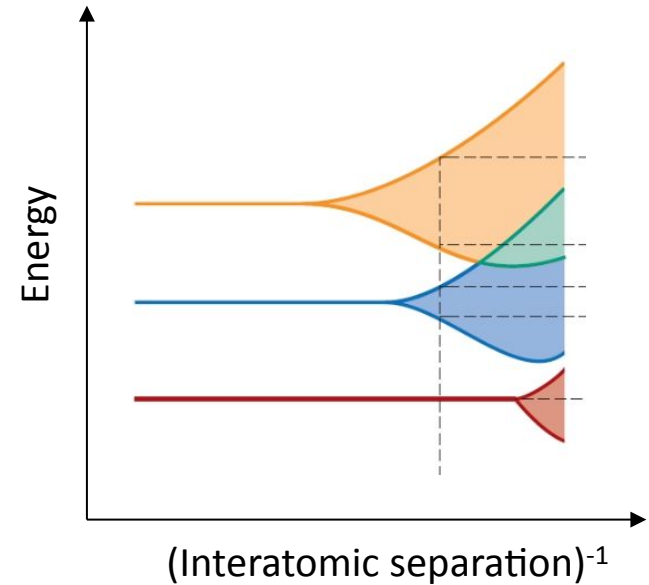
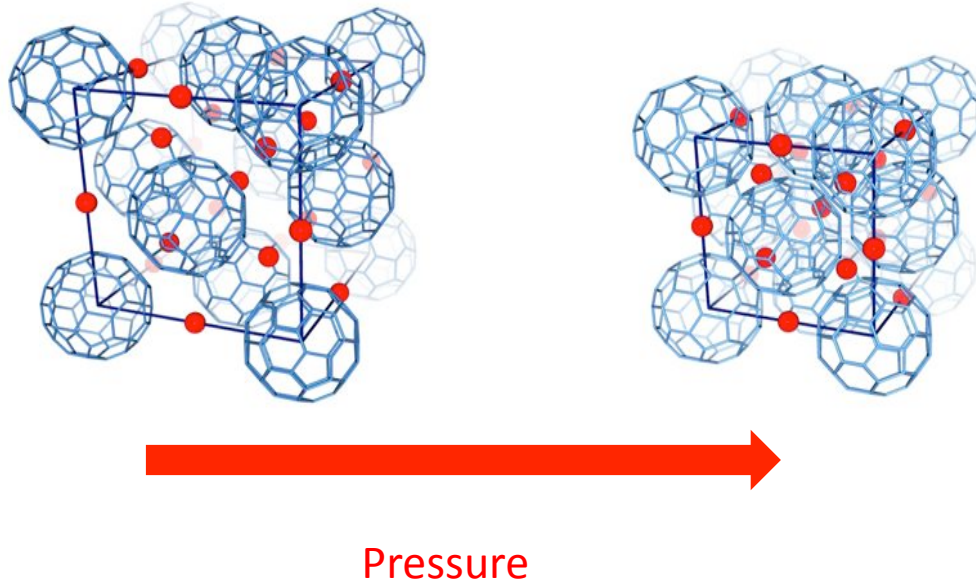
Application of external pressure



Application of external pressure



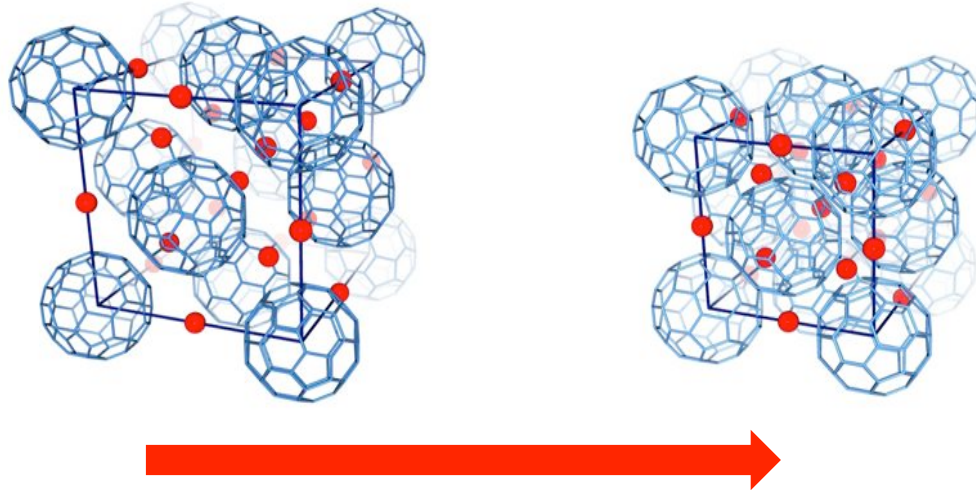
Pressure on conventional superconductors



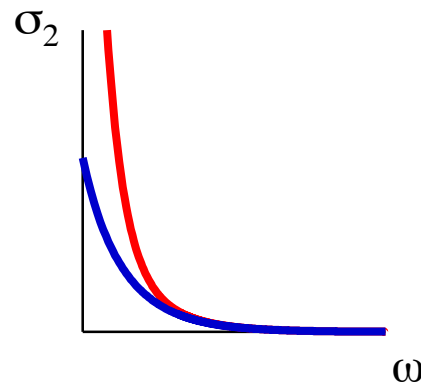
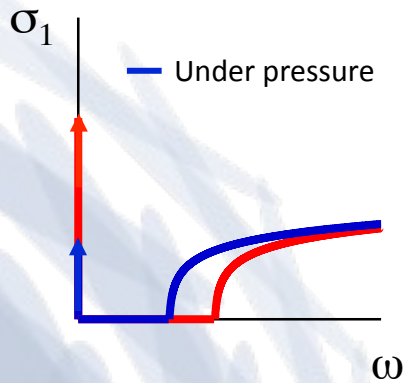
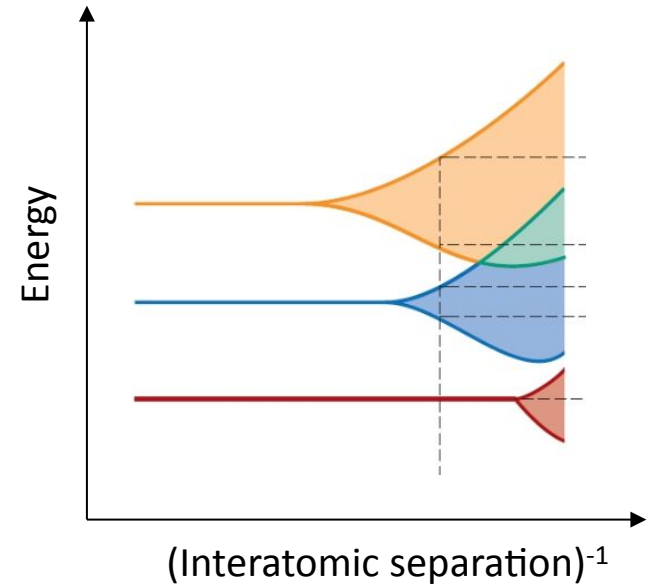
- K_3C_{60} soft material
- Sizable bandwidth (W) change
- Molecular structure unaffected

$$N(E_f) \sim 1/W$$

Pressure on conventional superconductors mpsd

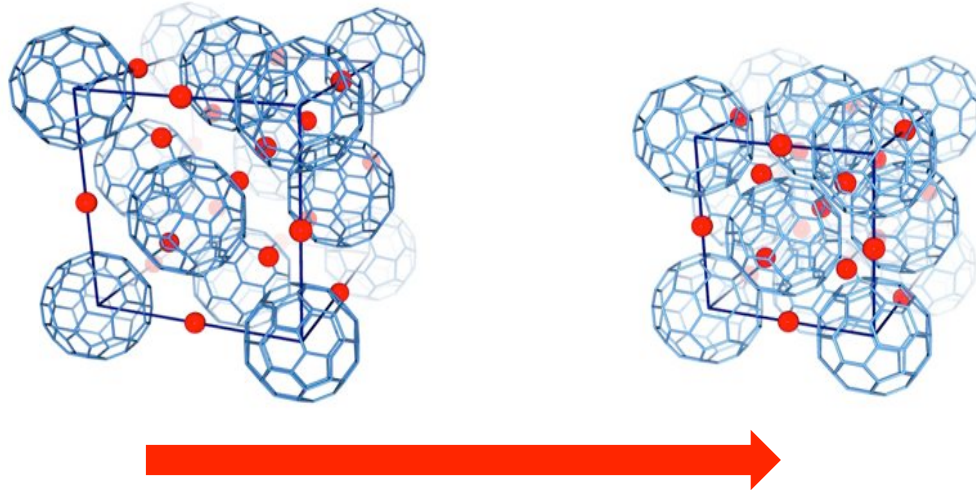


Pressure

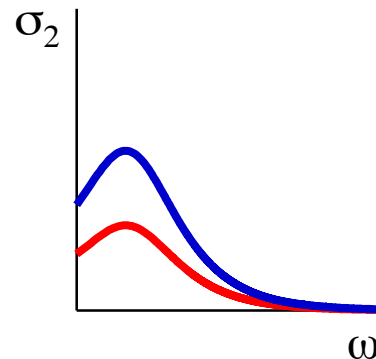
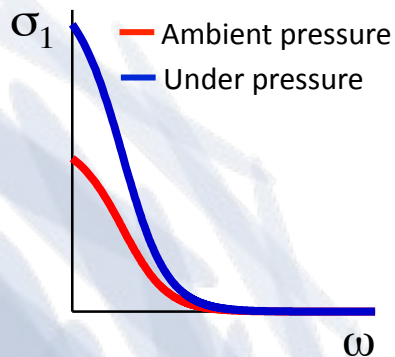
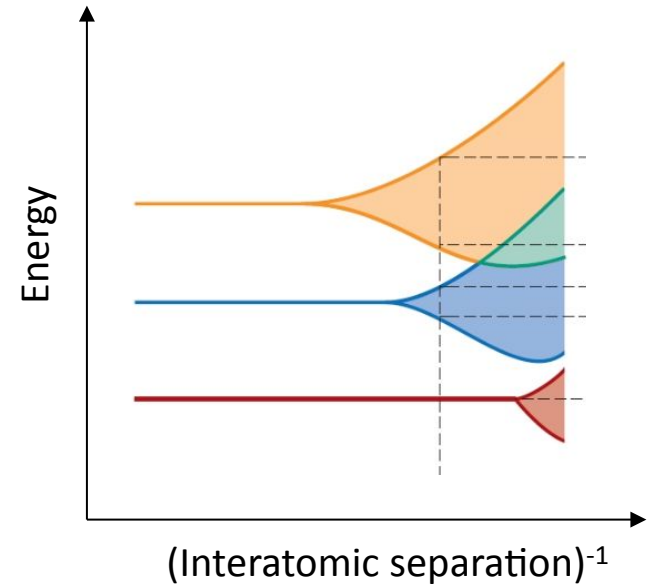


$$T_c \propto \Delta \propto e^{-\frac{1}{N(E_f)}}$$

Pressure on metallic states

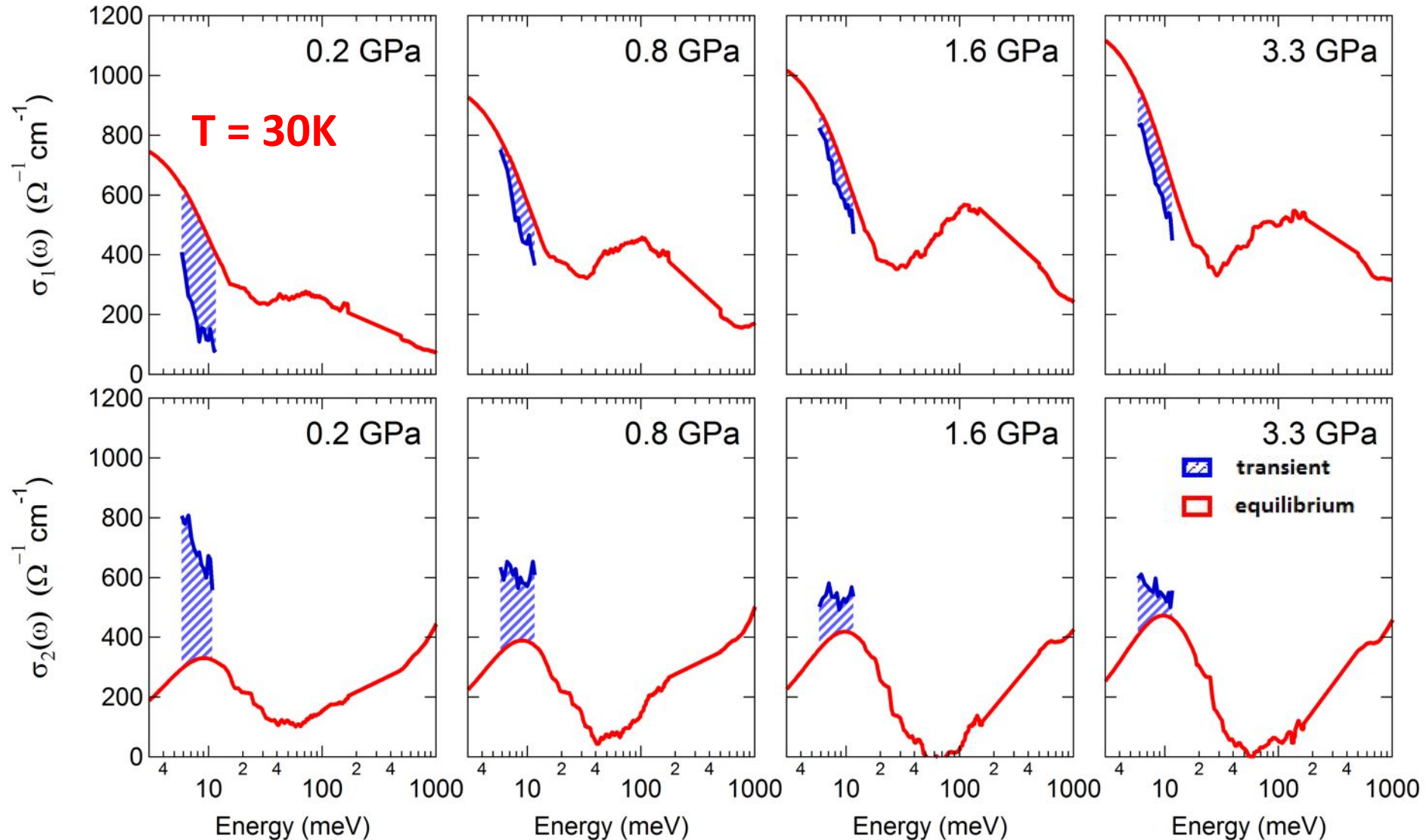


Pressure

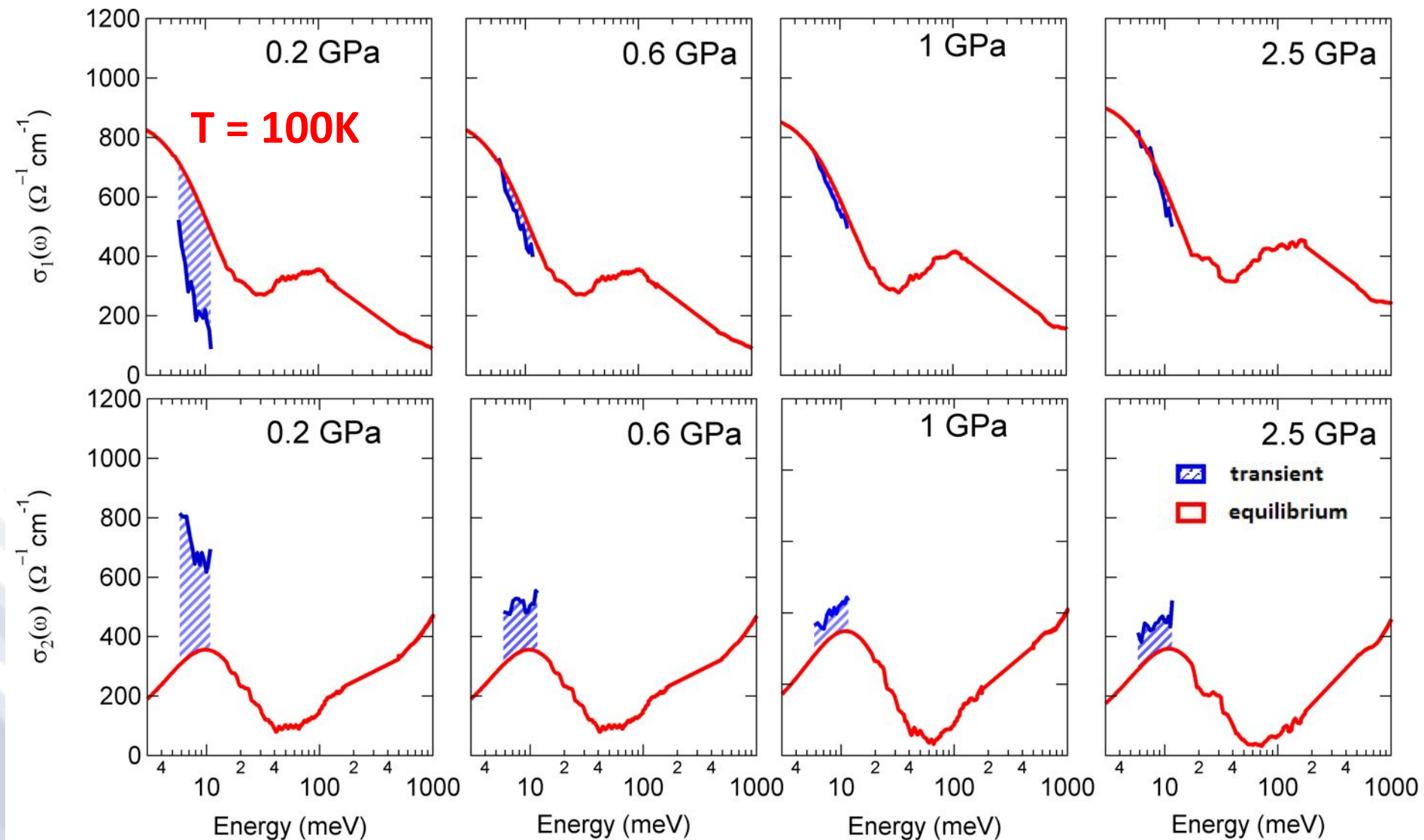


$$\sigma_{dc} \propto \omega_p^2 \propto \frac{N}{m_{eff}}$$

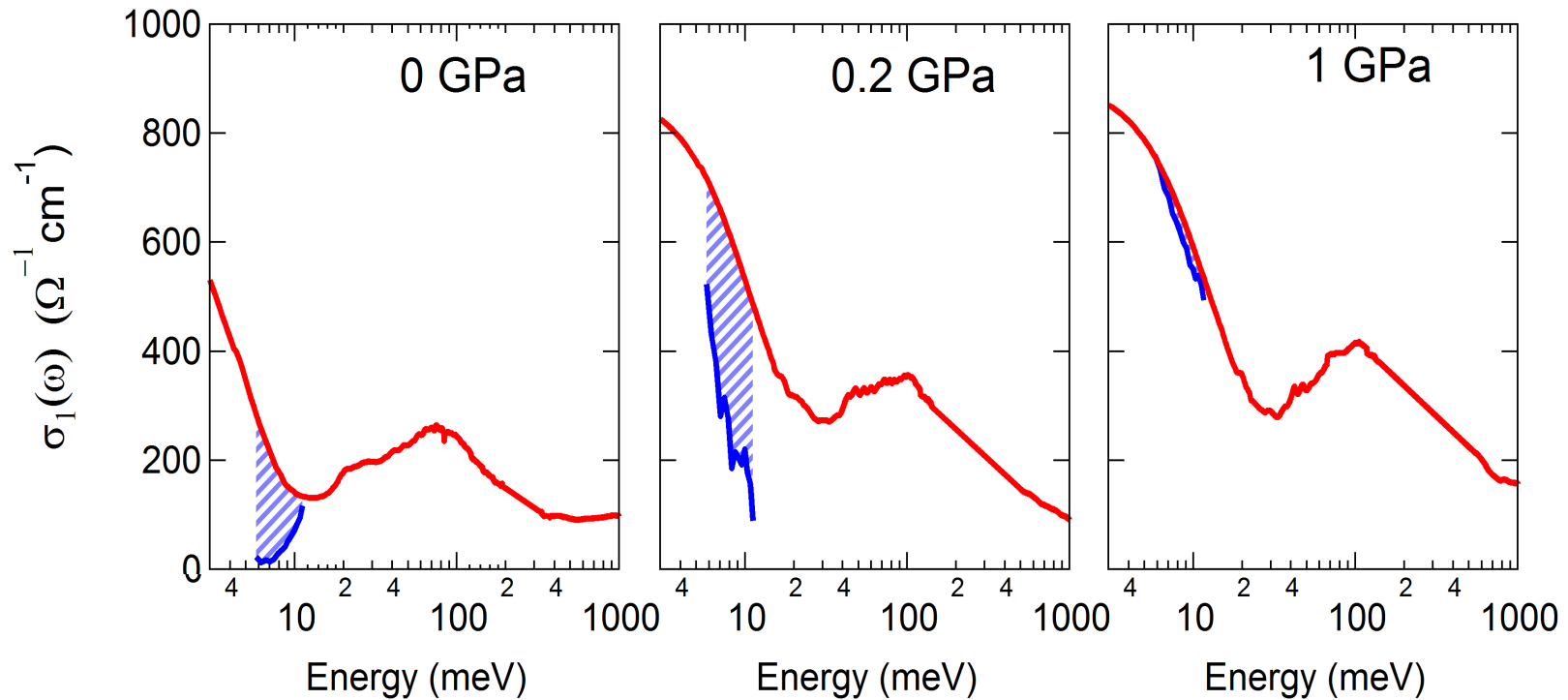
Transient phase suppressed by pressure



Transient phase suppressed by pressure

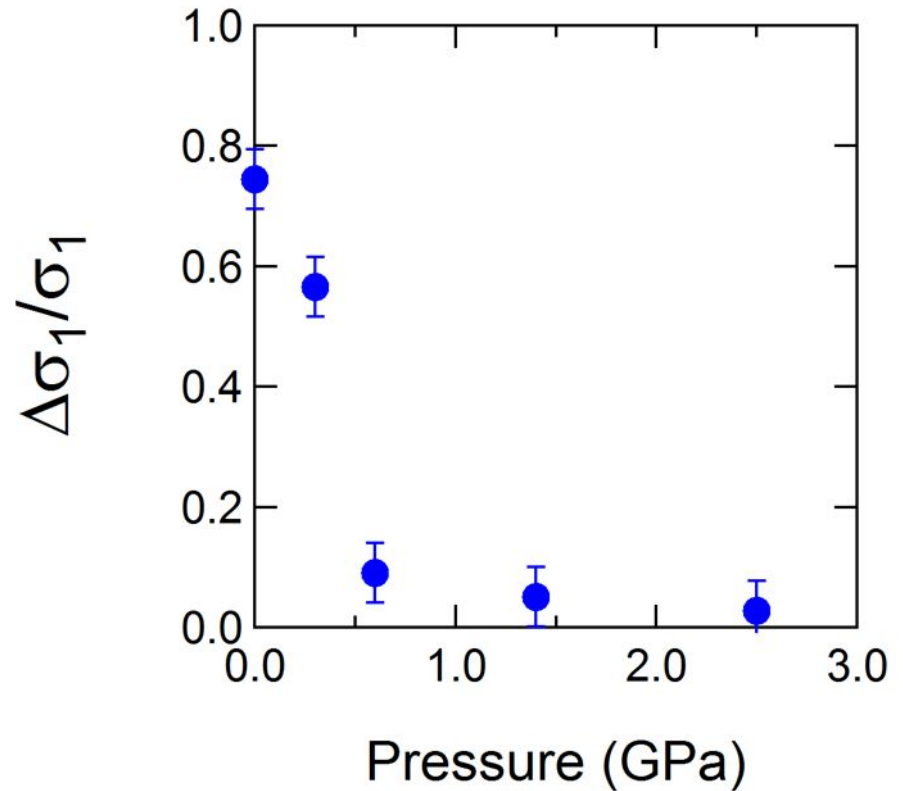
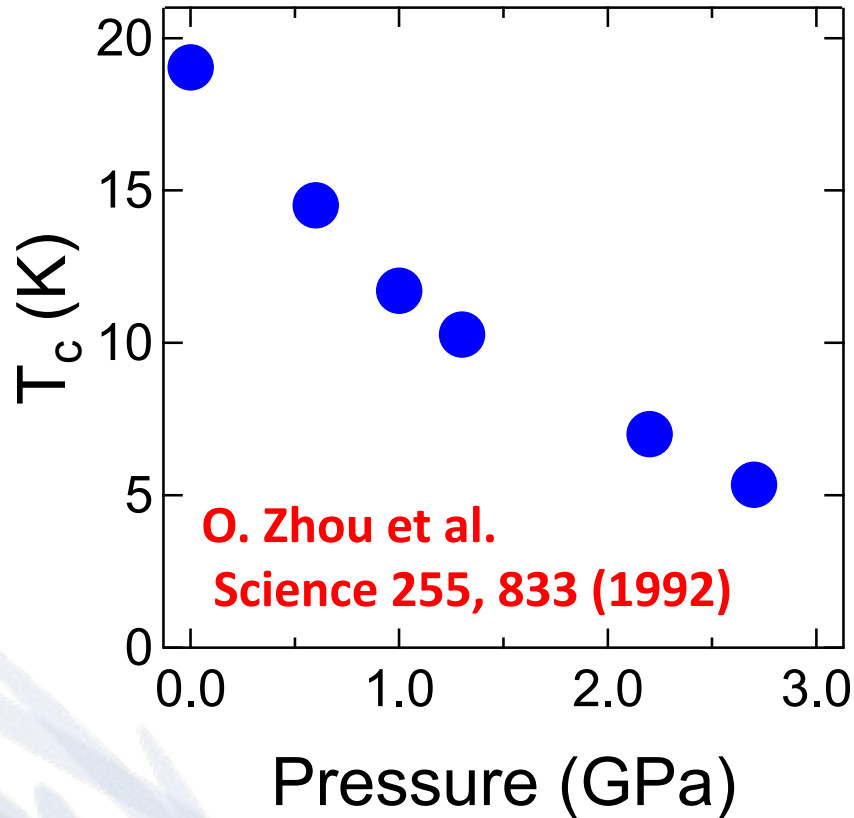


Light-induced gap drops with pressure



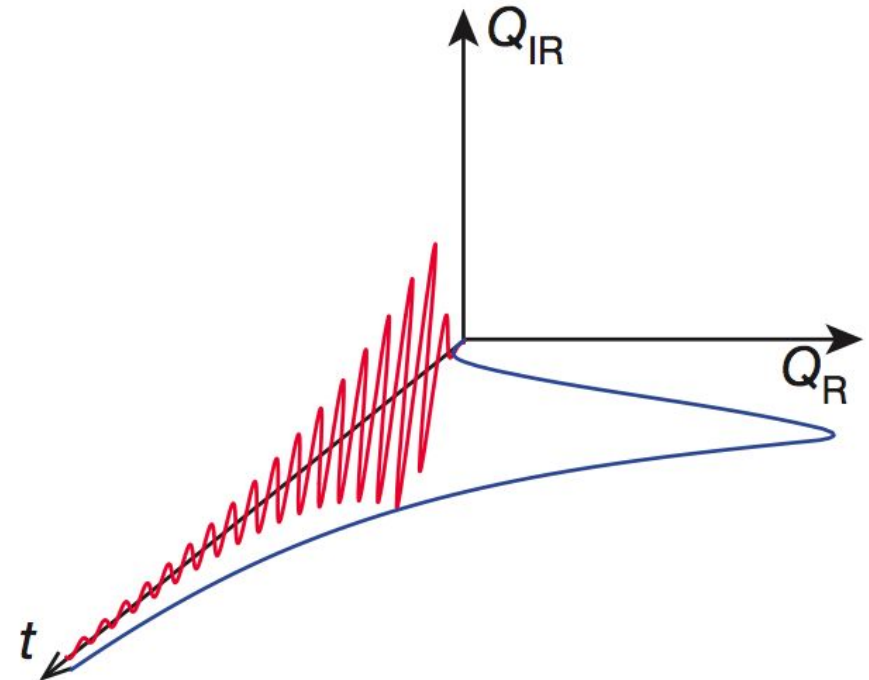
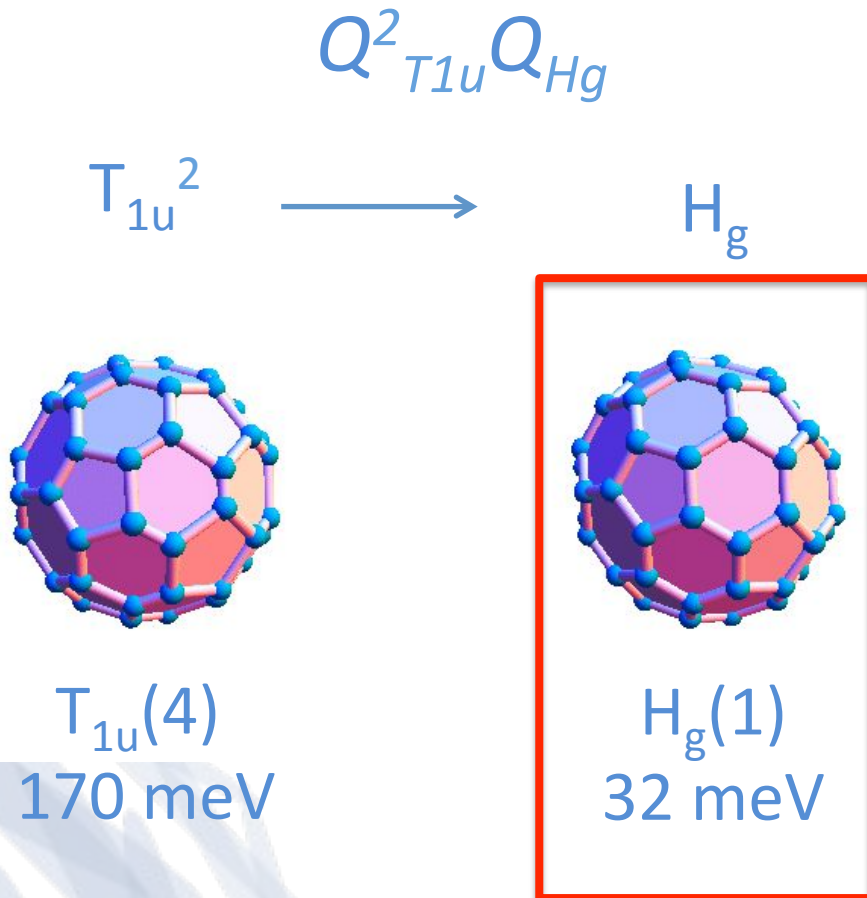
The photoinduced gap is dramatically suppressed with P

Light-induced gap drops with pressure



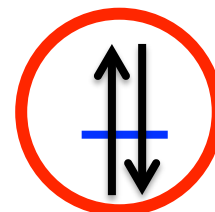
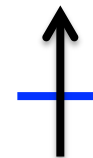
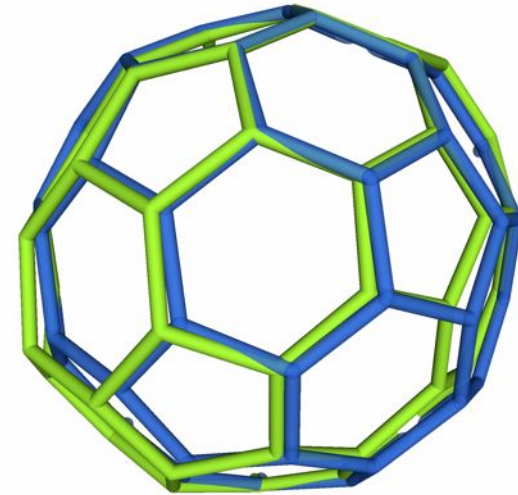
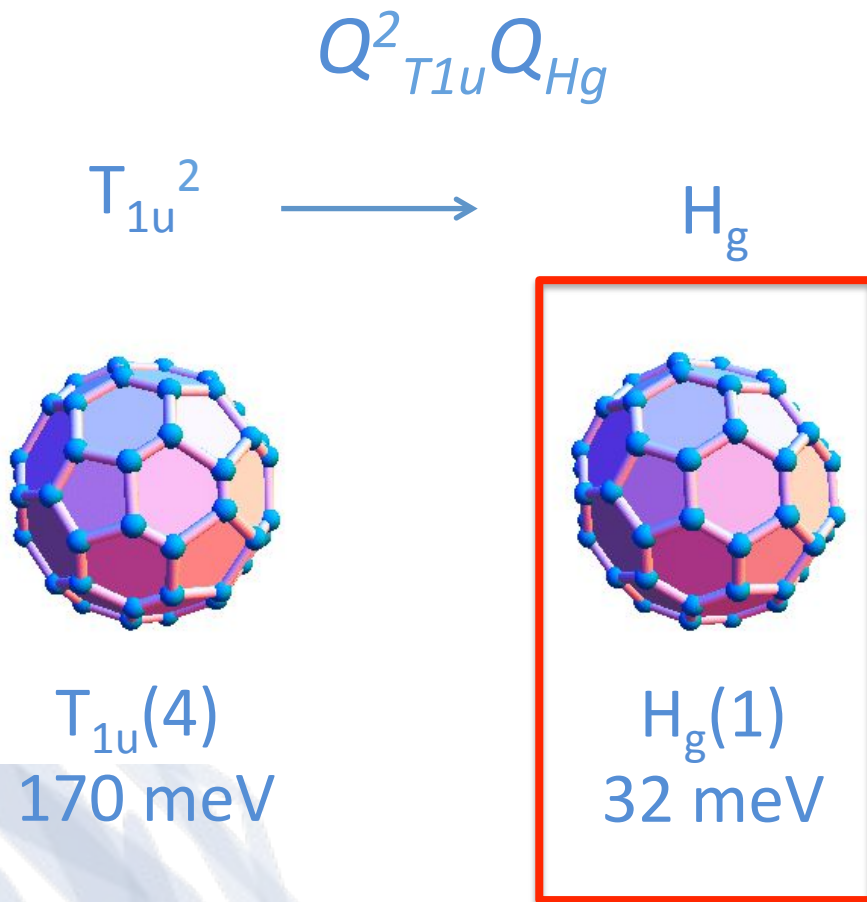
The photoinduced gap is dramatically suppressed with P
➔ Analogous to equilibrium superconducting phase

One possible mechanism



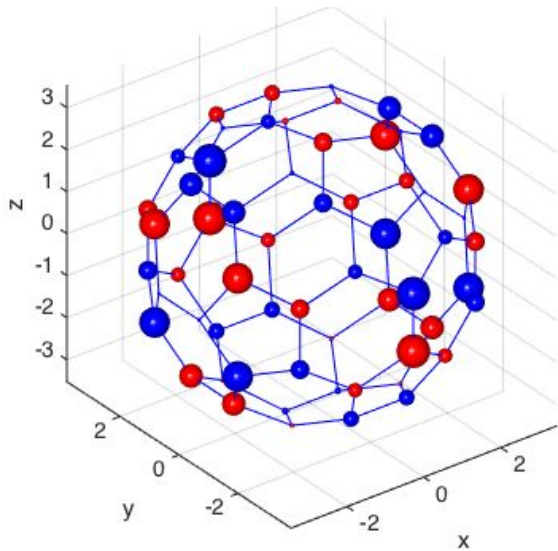
- M. Först et al., Nat. Phys. 7, 854 (2011)**
A. Subedi et al., PRB 89, 220301 (2014)
M. Först et al., Acc. Chem. Res. 48, 380 (2015)

One possible mechanism

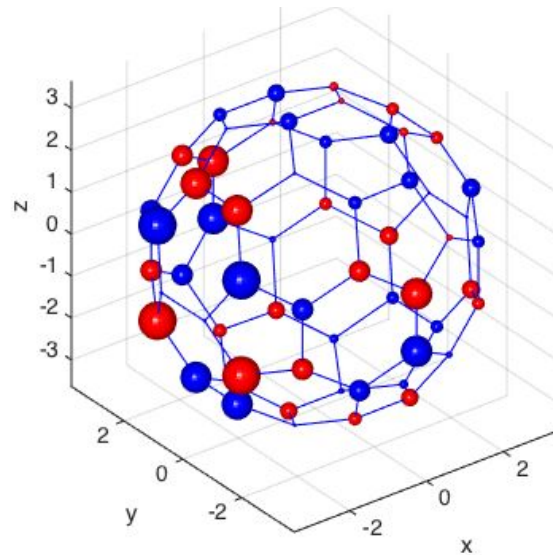


An alternative mechanism

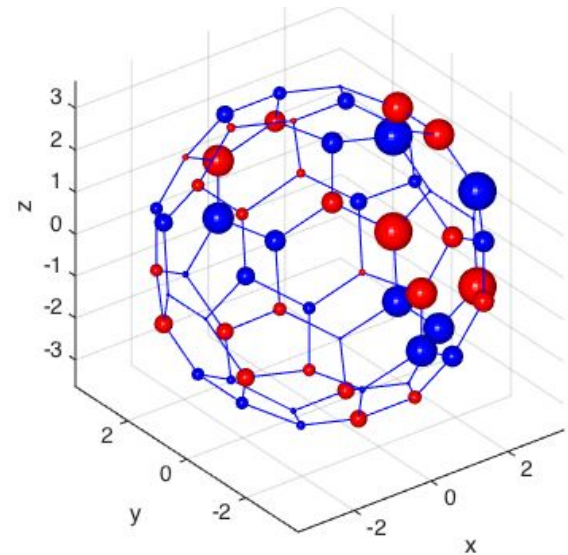
$t/\tau=0$



$t/\tau=1/4$

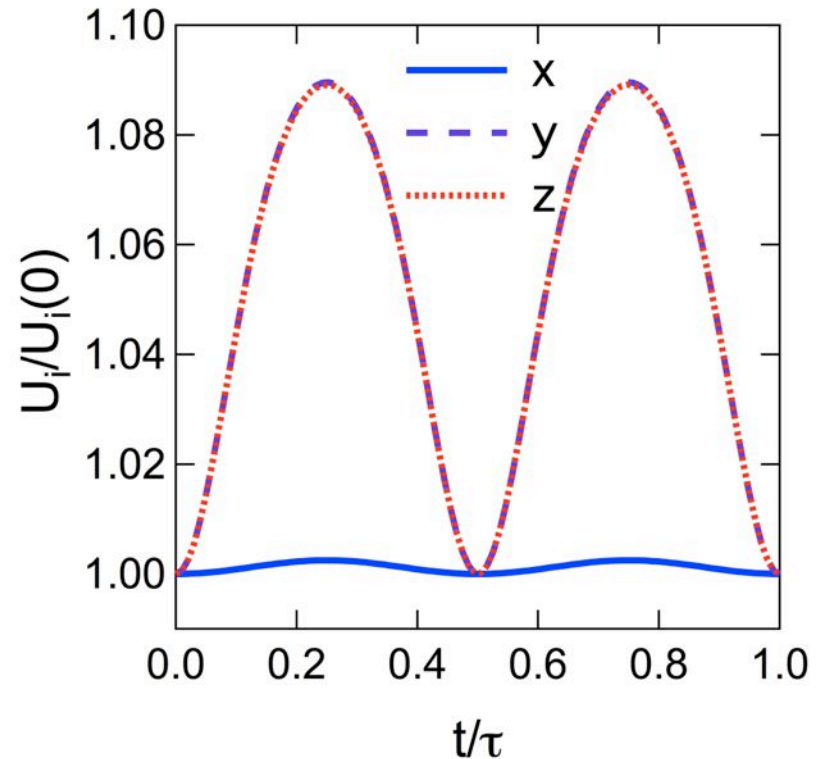
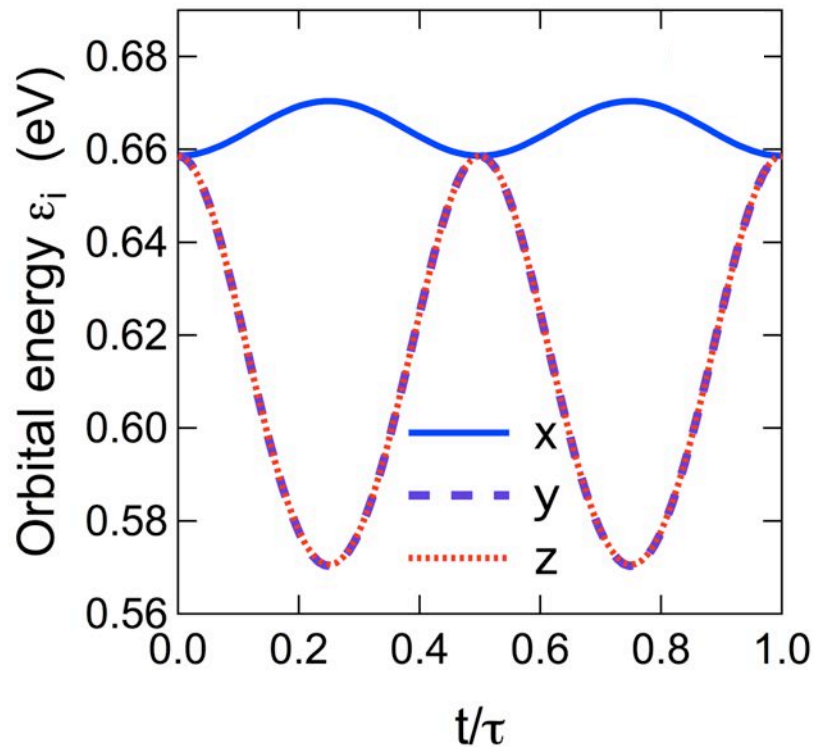


$t/\tau=3/4$



Local charge density is modified by the pump

An alternative mechanism



Effective Coulomb repulsion will be modulated
(More in M. Kim and S. R. Clark talks)

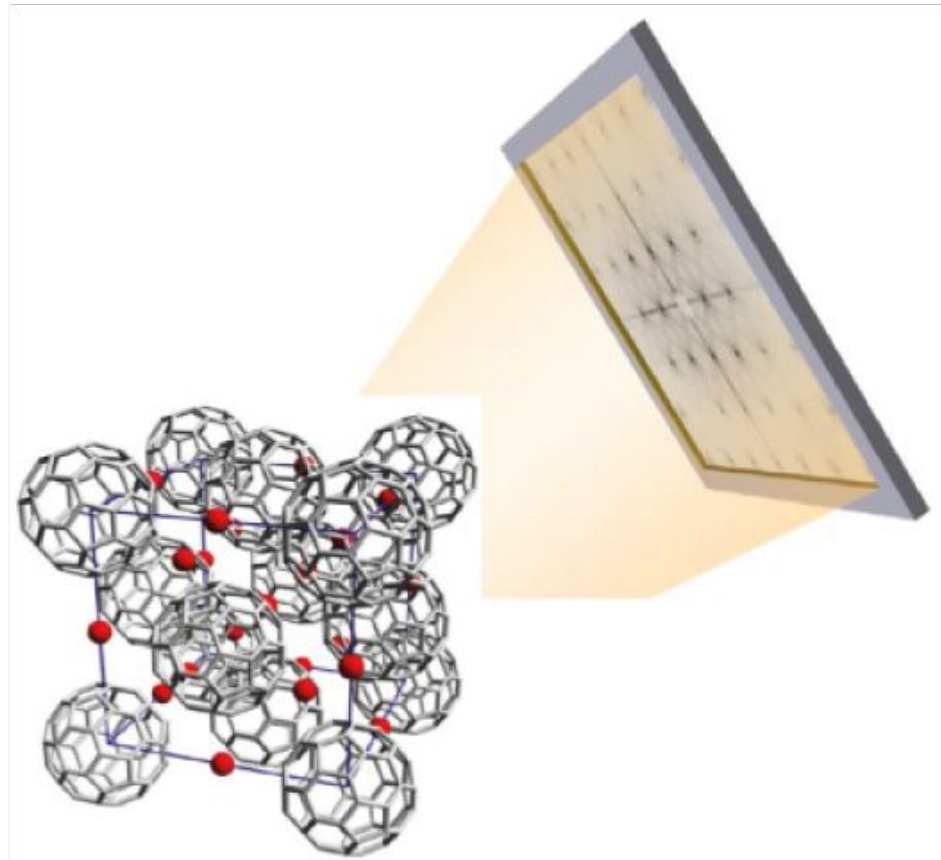
What's next? Ultrafast X-ray Diffraction

MIR Pump – X-ray Diffraction Probe experiment at LCLS

Hard x-ray probe
50fs - 10keV

Mid-IR excitation

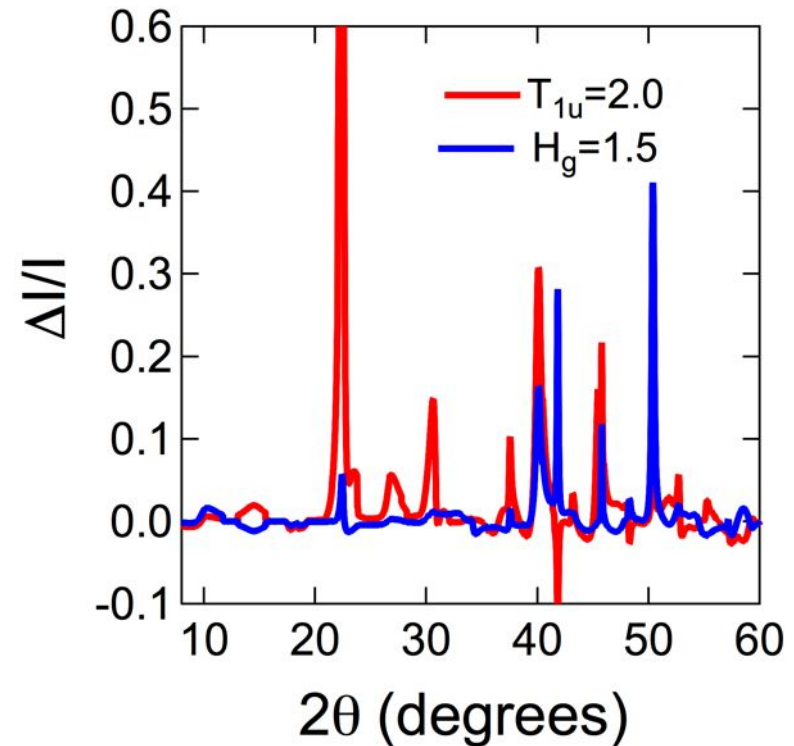
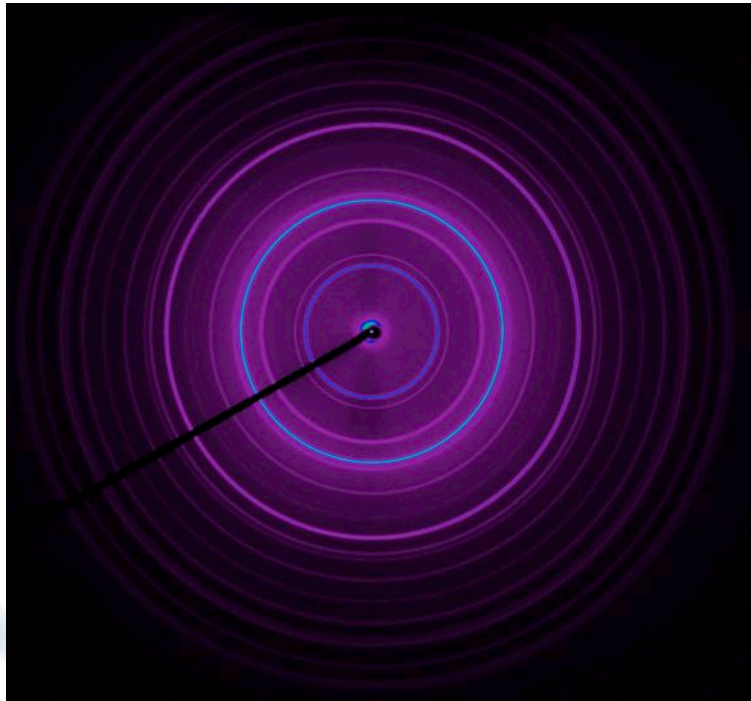
7.3 μm - 200fs



Probe the transient crystal structure

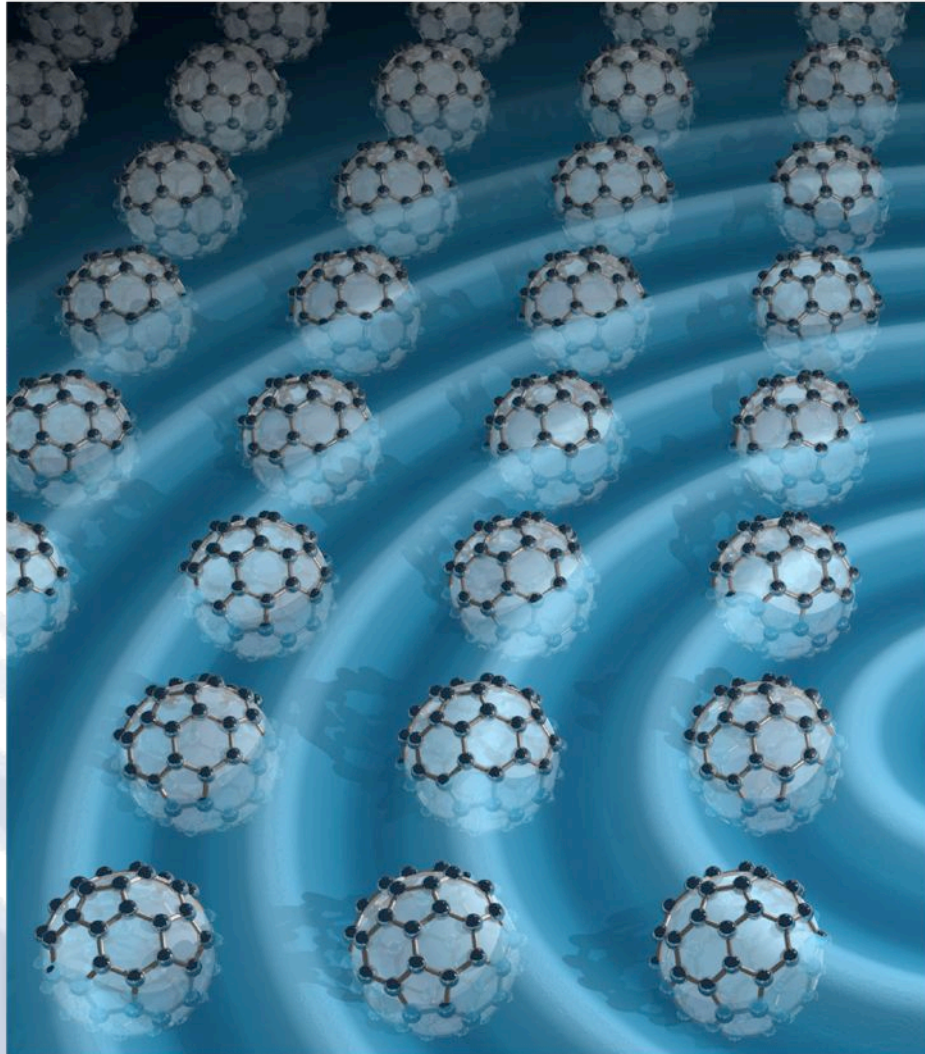
What's next? Ultrafast X-ray Diffraction

Goal: discriminate between microscopic mechanisms



- H_g distortion: nonlinear phonon coupling
- T_u distortion only: dominant electronic correlations

Summary



- Light-induced gapped phase in metallic K_3C_{60}
- Superconducting-like pressure dependence
- Upcoming X-rays to address microscopic mechanism

Acknowledgements

Equilibrium IR

Andrea Perucchi
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Stefano Lupi
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Alice Cantaluppi



Michele Buzzi



Andrea Cavalleri

Samples

Mauro Riccò
Daniele Pontiroli
(Parma, Phys. Dept.)



Stefan Kaiser

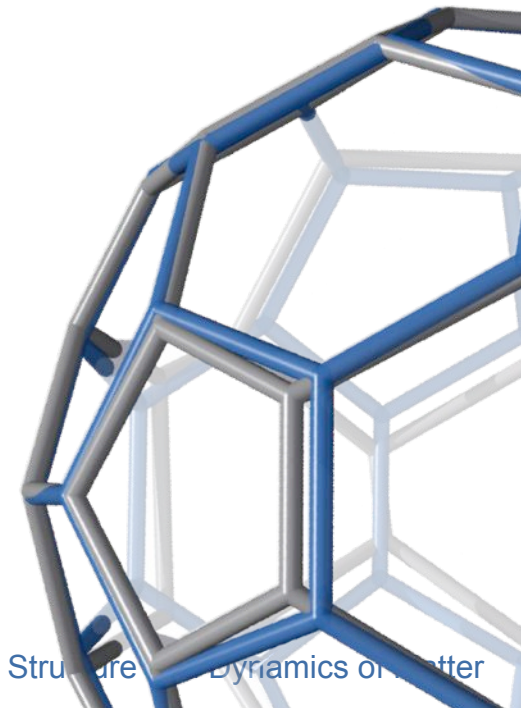


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Theory

Stephen R. Clark
Dieter Jaksch
(Oxford, UK)

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Thank you for your attention!