



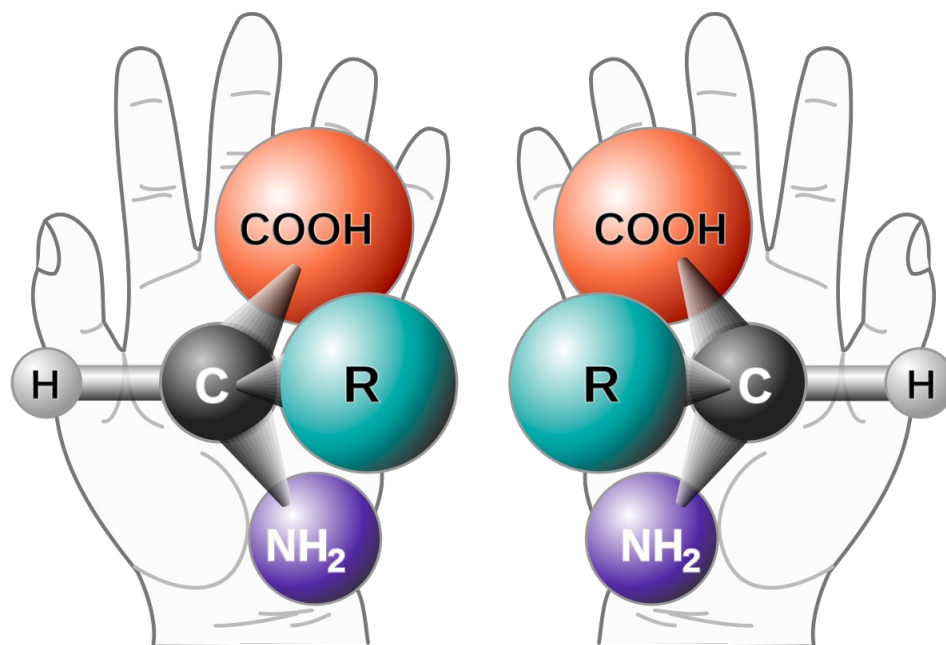
# Ultrafast meets chirality

Samuel Beaulieu  
Ph.D. UBordeaux and INRS

Fritz-Haber-Institut  
der Max-Planck-Gesellschaft

# What is chirality ?

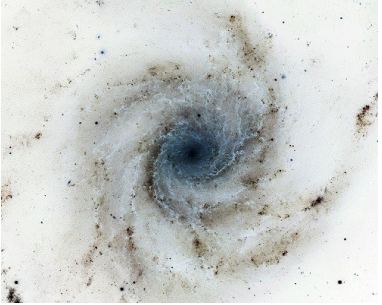
« A chiral phenomenon or object is not identical to its mirror image. »



greek χείρ, ch[e]ir : hand

# Chirality

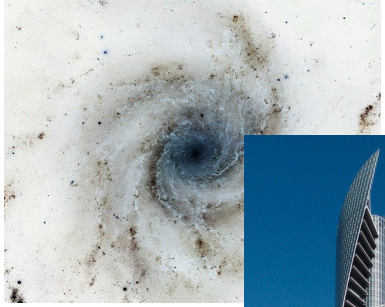
Fundamental broken symmetry in nature.



Galaxy

# Chirality

Fundamental broken symmetry in nature.



Galaxy

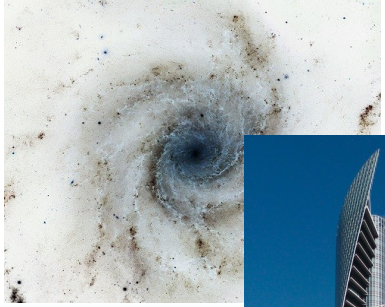


Building

Mode Gakuen Spiral tower  
Nagoya, Japon

# Chirality

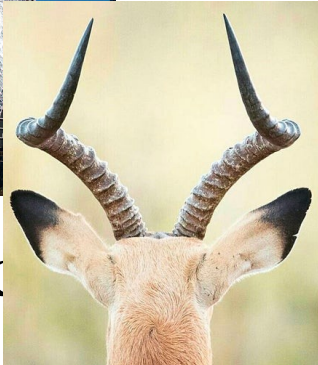
Fundamental broken symmetry in nature.



Galaxy



Building

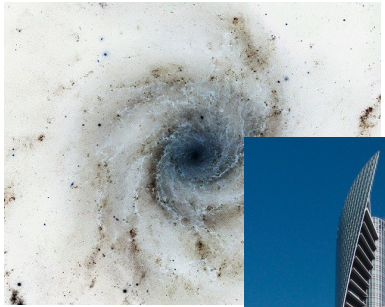


Animal

Impala  
(*Aepyceros melampus*)

# Chirality

Fundamental broken symmetry in nature.



Galaxy



Build



Anim

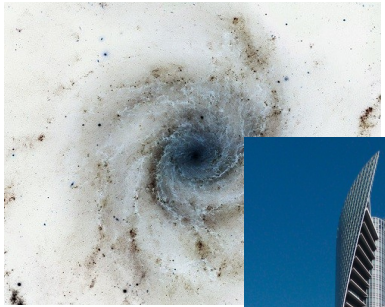


Snail



# Chirality

Fundamental broken symmetry in nature.



Galaxy



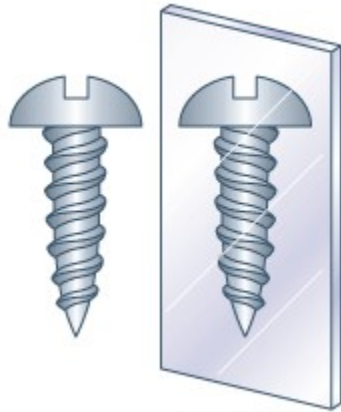
Building



Animal



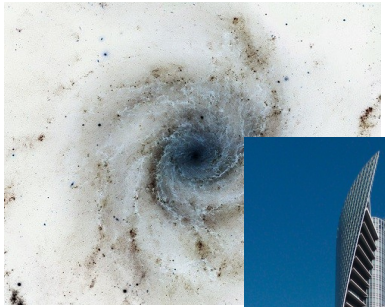
Snail



Screw

# Chirality

Fundamental broken symmetry in nature.



Galaxy



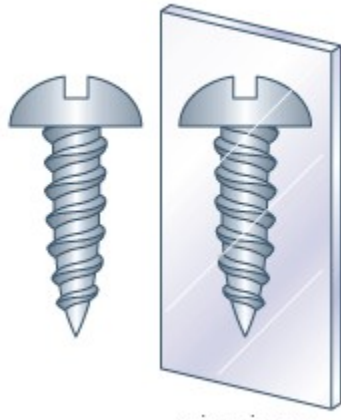
Building



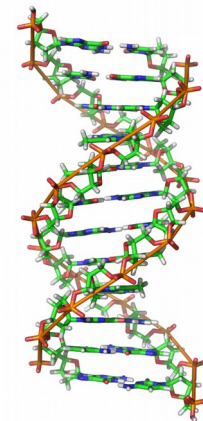
Animal



Snail



Screw

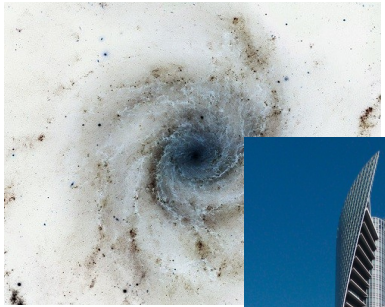


DNA



# Chirality

Fundamental broken symmetry in nature.



Galaxy



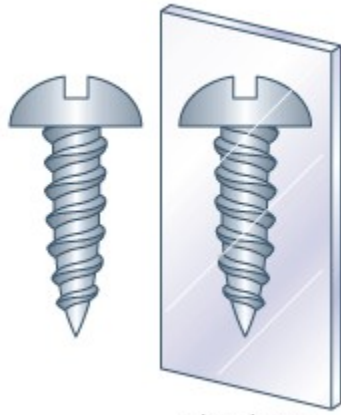
Building



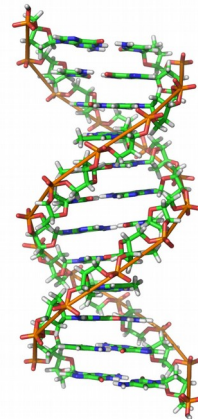
Animal



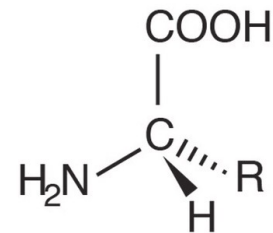
Snail



Screw



DNA



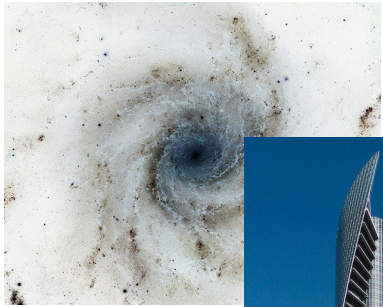
Molecule

# Chirality

Fundamental broken symmetry in nature.

...can emerge at any length scale.

Ubiquitous from astrophysics, to architecture  
to molecular physics.



Galaxy



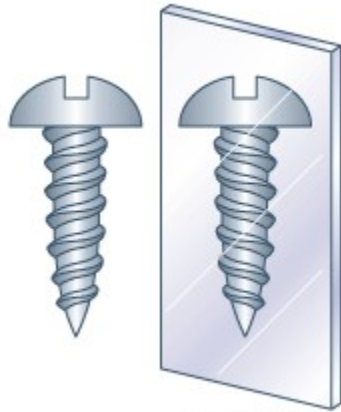
Building



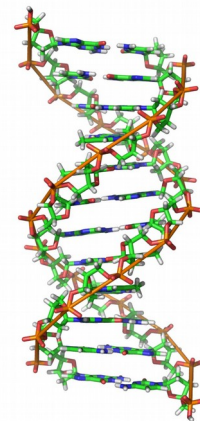
Animal



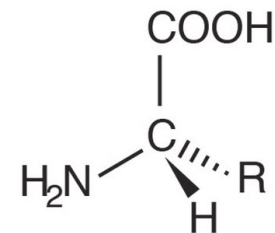
Snail



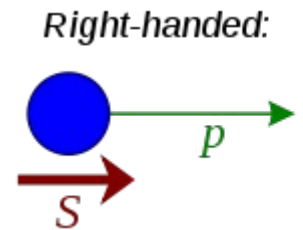
Screw



DNA



Molecule



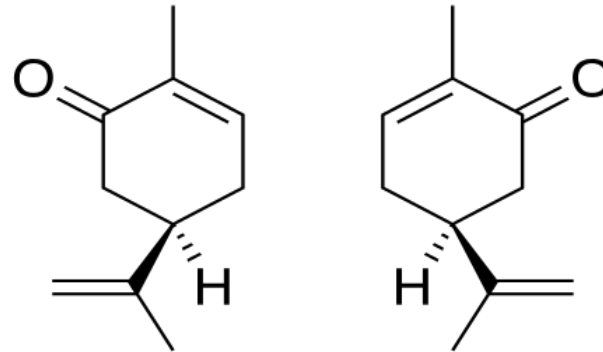
Subatomic

# Chirality

A chiral object can be discriminated via its interaction with another chiral object.

How to do this in the lab ?

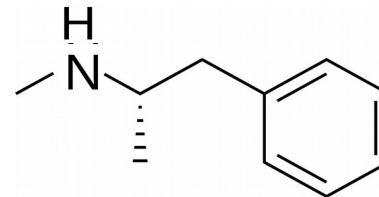
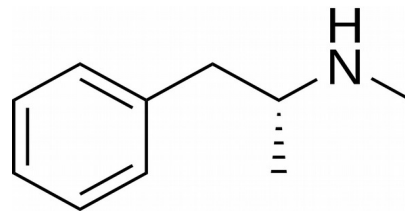
Mint



Dill



Nasal decongestant

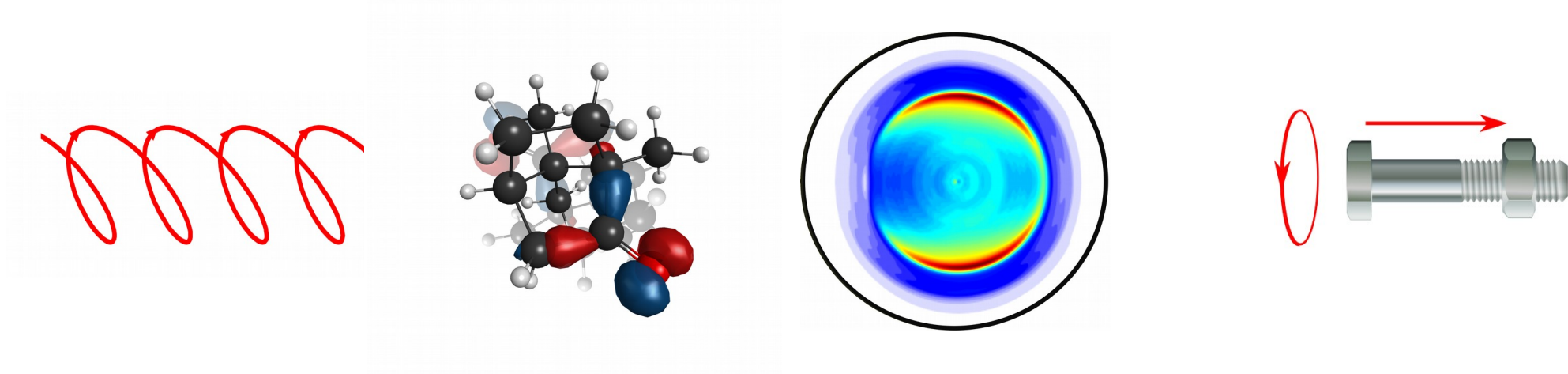


Meth



# Photoelectron Circular Dichroism

Left

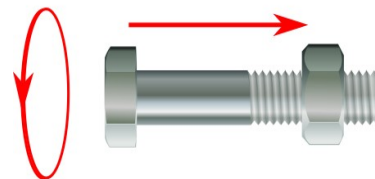
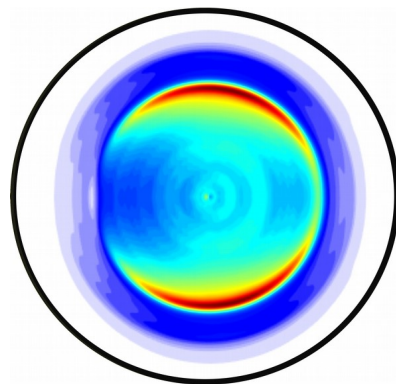
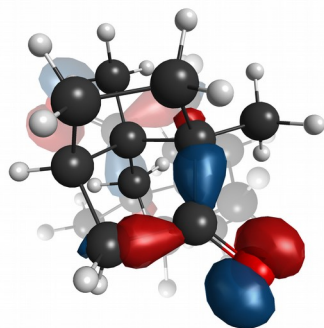
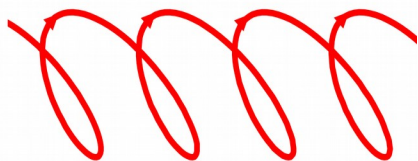


Circularly polarized light is chiral.

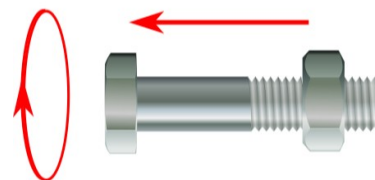
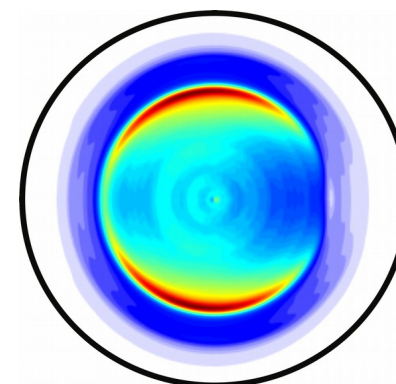
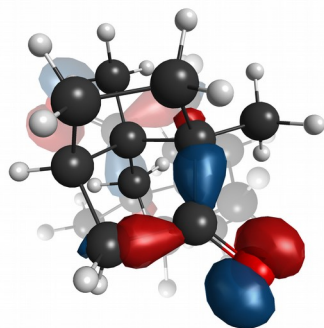
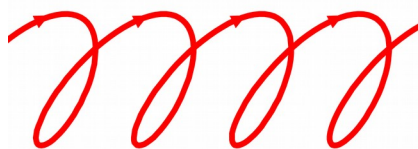


# Photoelectron Circular Dichroism

Left



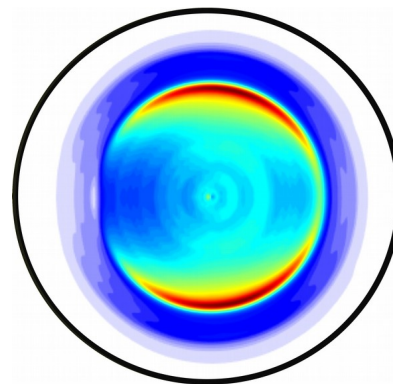
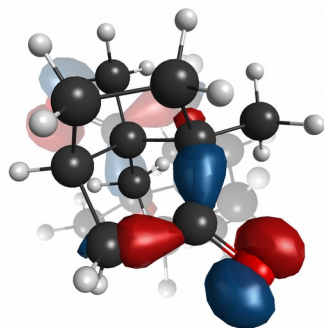
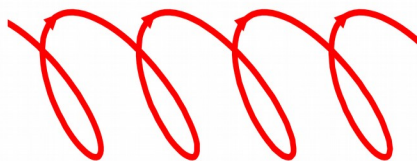
Right



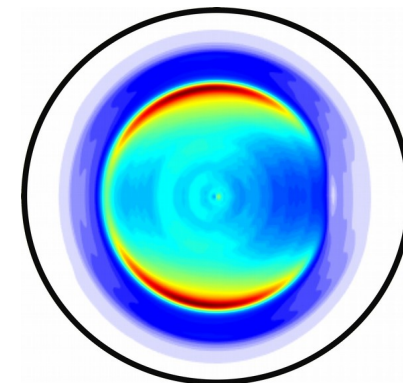
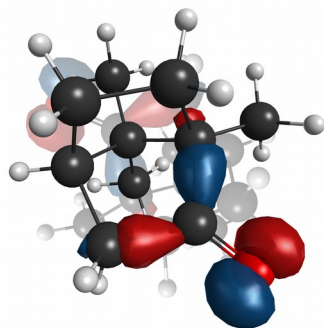
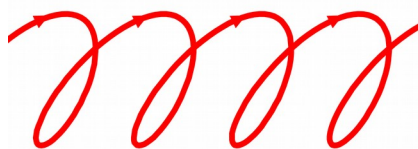
The asymmetry reverses if the molecular or the light handedness is changed

# Photoelectron Circular Dichroism

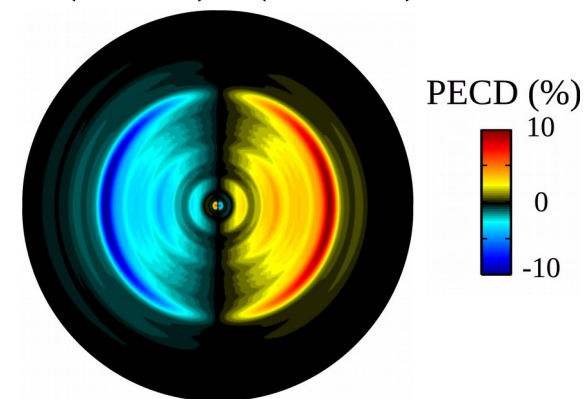
Left



Right



$$2(L-R)/(L+R)$$



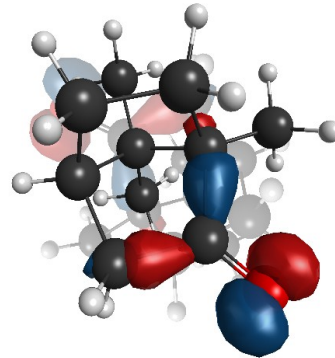
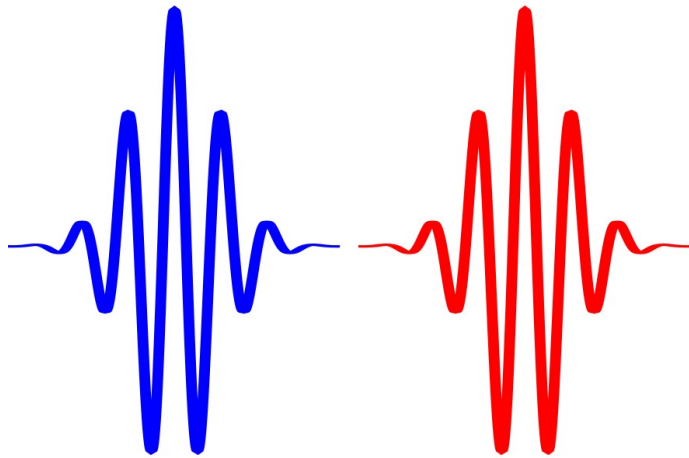
1-10 % asymmetry !

PECD has been studied in Synchrotron since 2001



# Ultrafast meets chirality

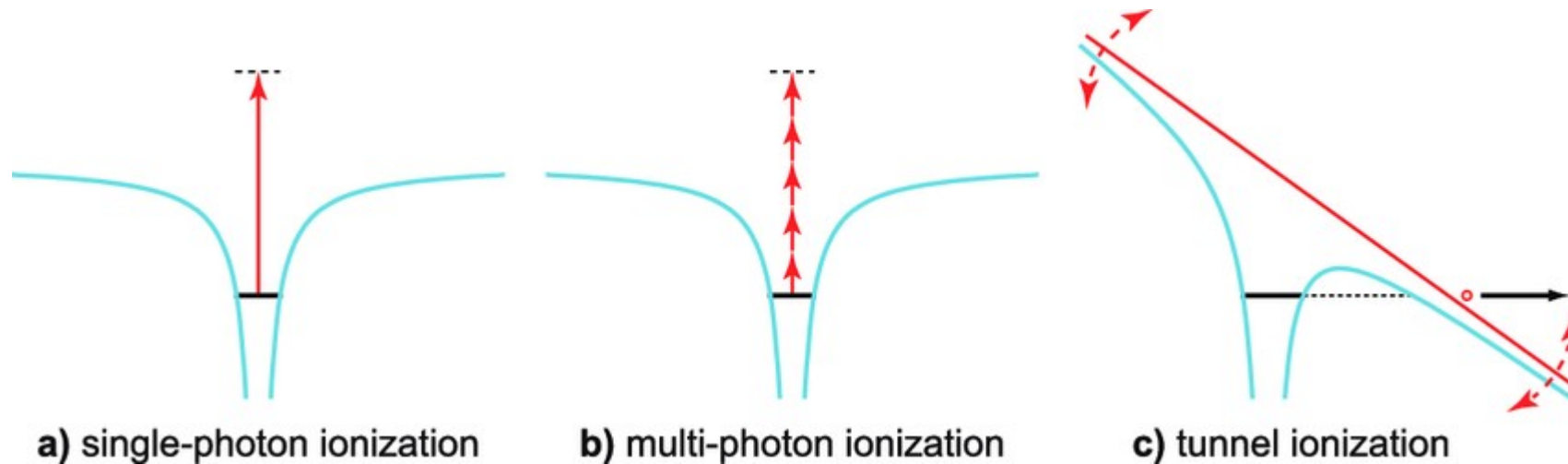
Using ultrafast (femtosecond =  $10^{-15}$  s) laser pulse to study molecular chirality



- Different ionization regime
- Ultrafast temporal resolution (pump-probe)
- Access to delays in the photoelectric effect

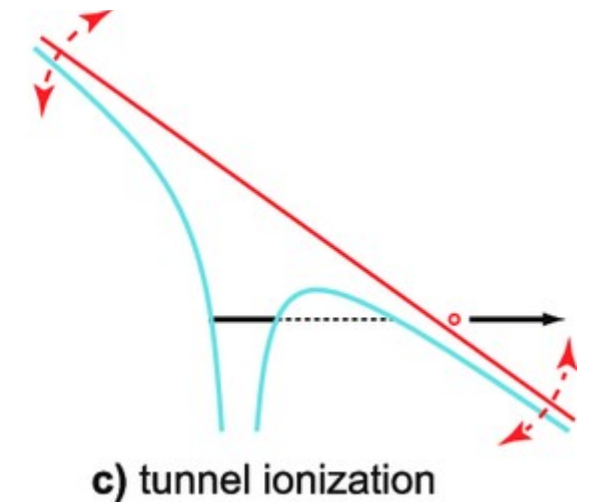
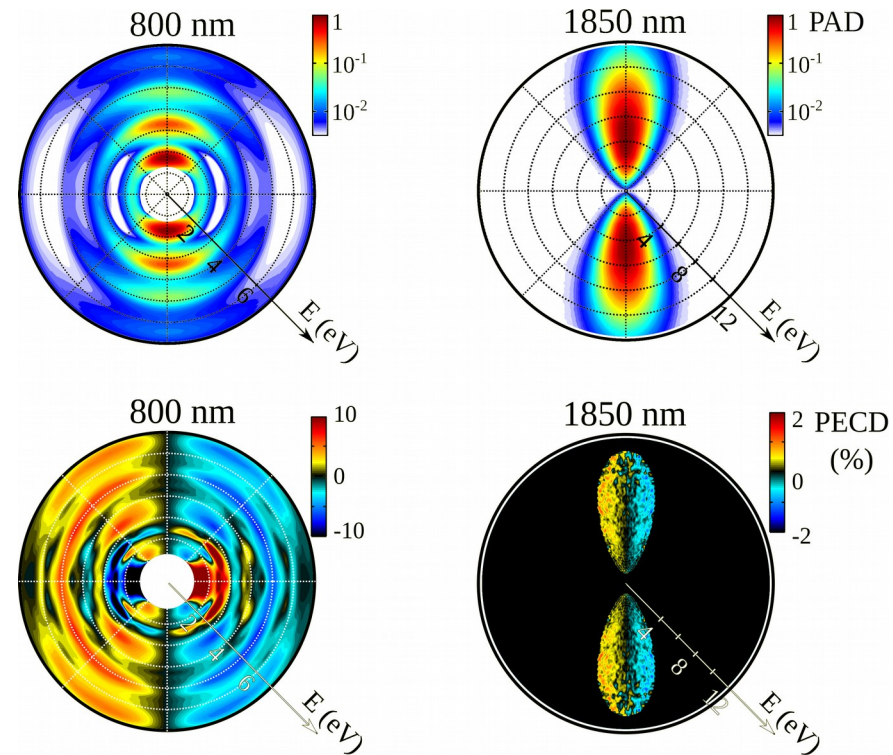
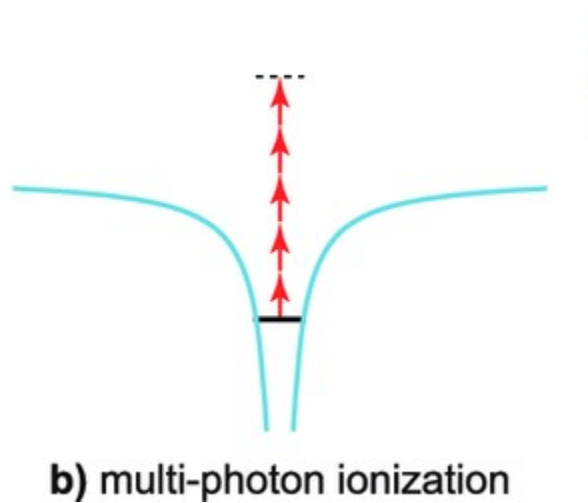
# Ultrafast meets chirality : Question #1

Does PECD exists in all ionization regime ?



# Ultrafast meets chirality : Question #1

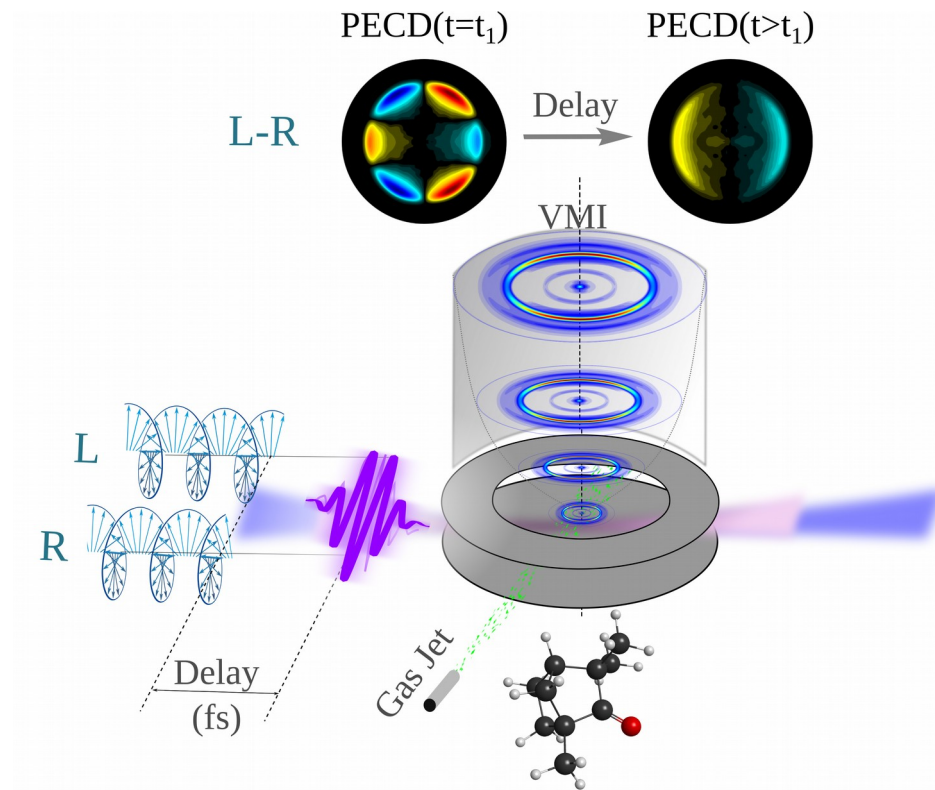
Does PECD exists in all ionization regime ?



We can use the strong-field/attosecond science toolbox to study chirality.

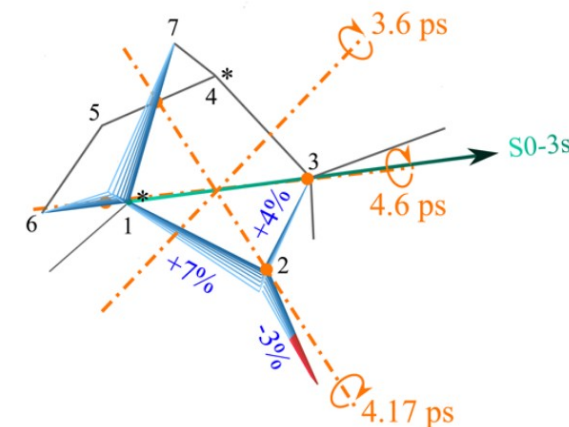
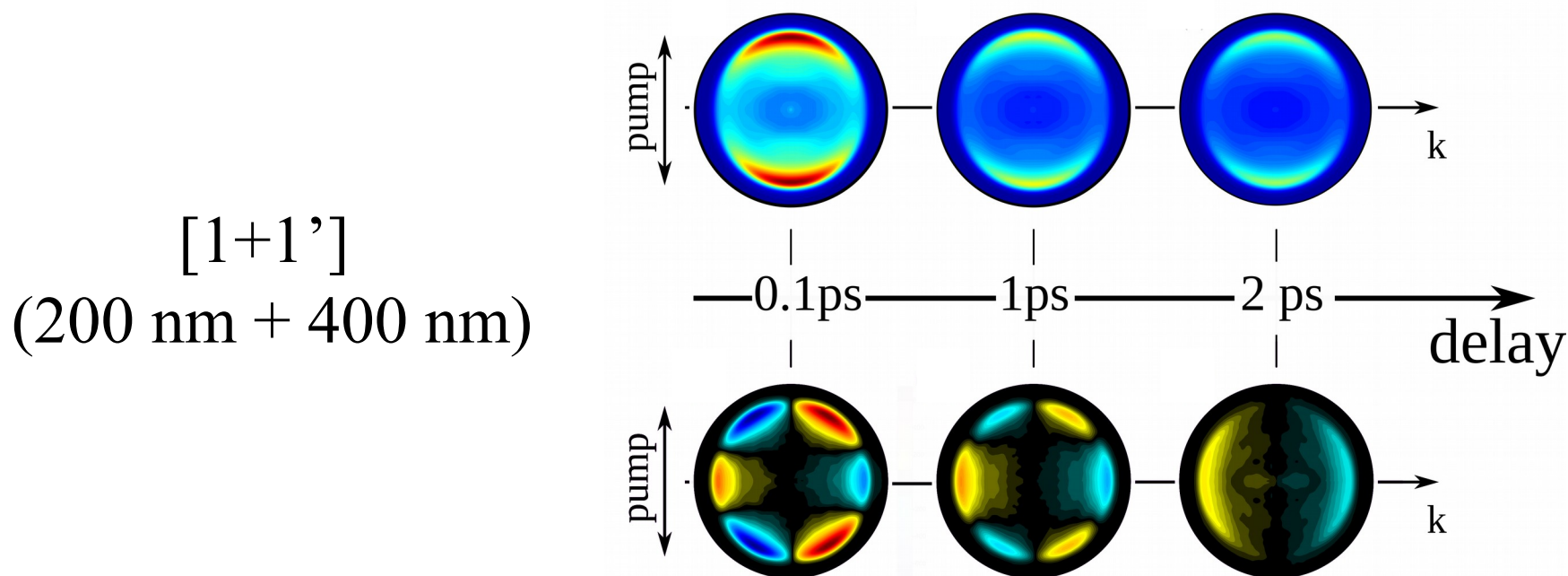
## Ultrafast meets chirality : Question #2

Can we extend PECD to time-resolved studies of ultrafast molecular dynamics ?



# Ultrafast meets chirality : Question #2

(1R,4R)-(+)-Camphor



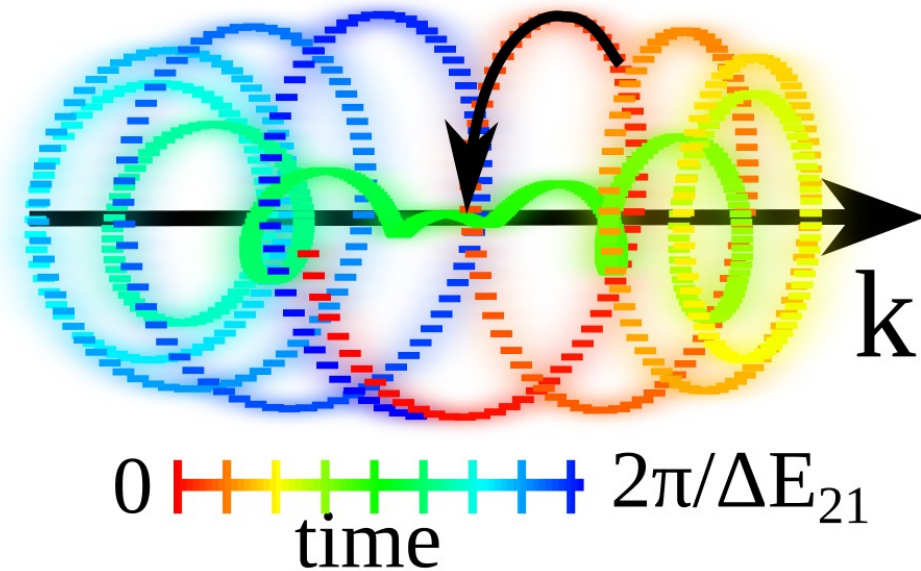
## Time-Resolved Photoelectron Circular Dichroism

Comby, Beaulieu *et al.*, JPCL **7**, 4514 (2016)

Beaulieu *et al.*, Faraday Disc. **194**, 325 (2016)

## Ultrafast meets chirality : Question #3

Can we create a forward-backward asymmetric electron distribution in bound states ?

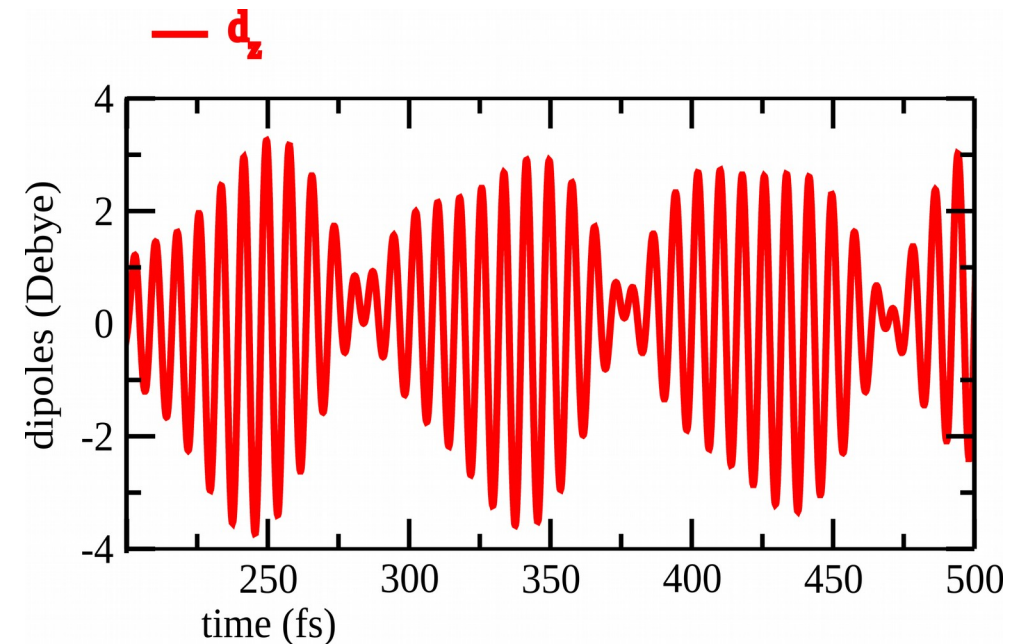
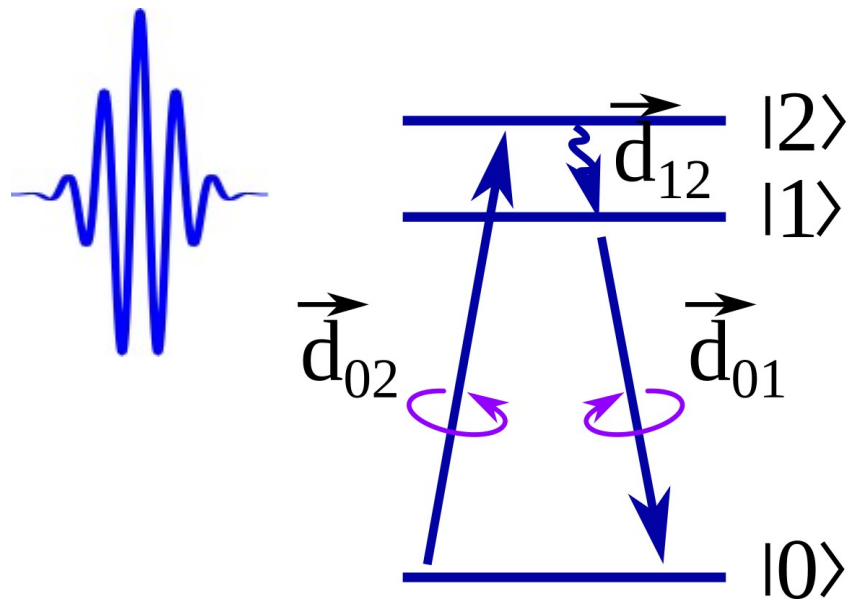




## Ultrafast meets chirality : Question #3

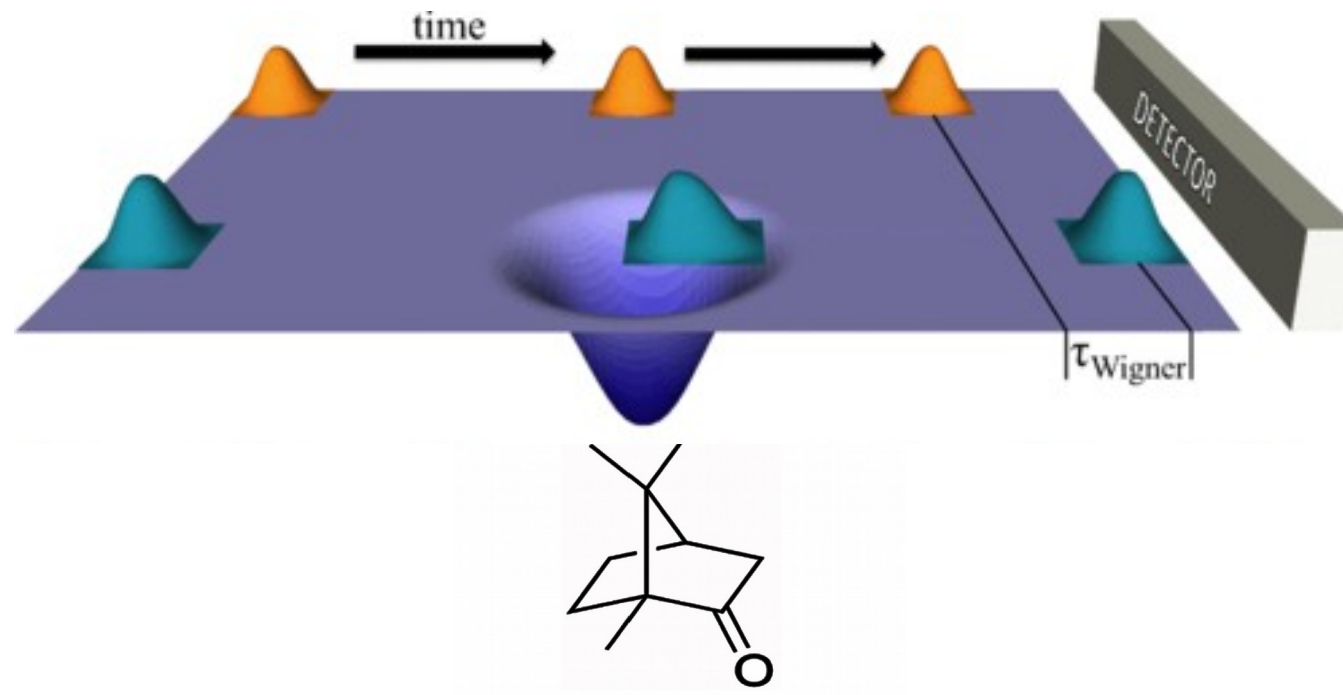


New chiroptical effect : Photoexcitation circular dichroism (PXCD)



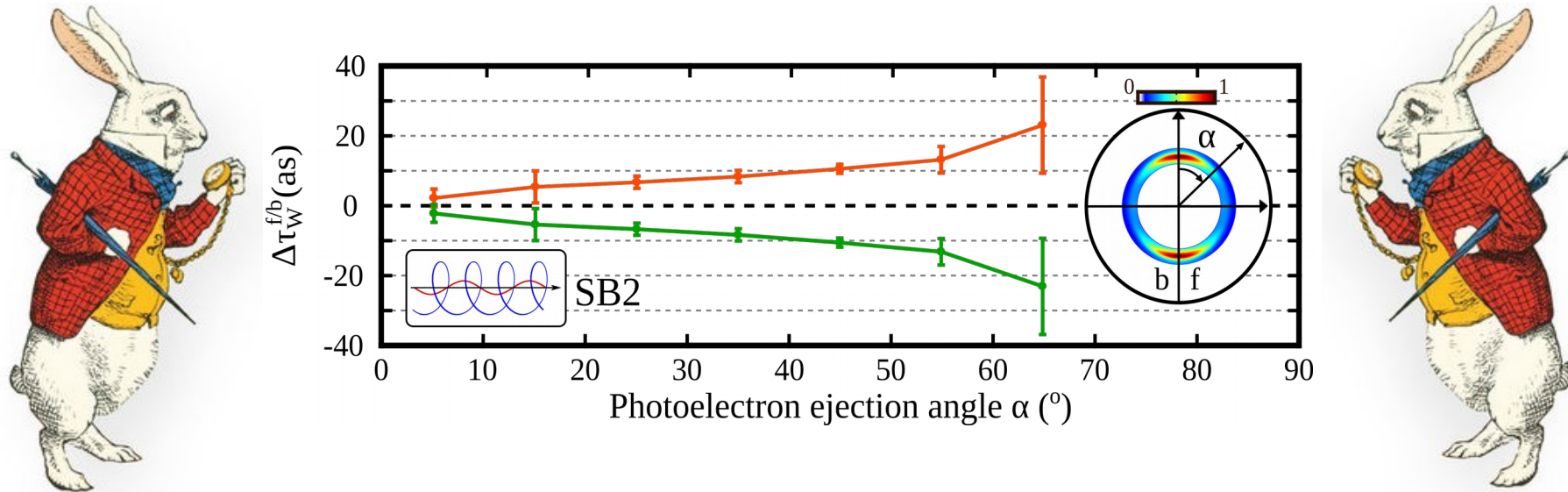
## Ultrafast meets chirality : Question #4

Chiroselectivity/asymmetry of photoionization time delays ?



# Ultrafast meets chirality : Question #4

Chiro-sensitivity/asymmetry of photoionization time delays ?

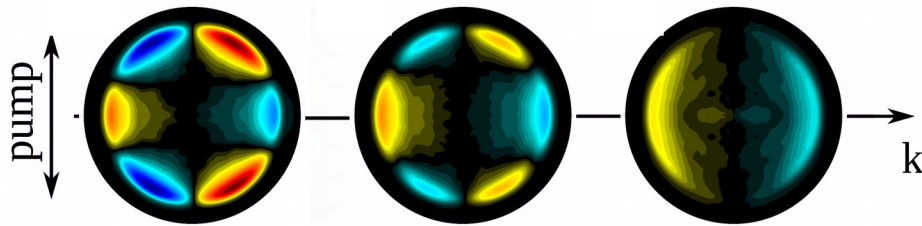


$$\Delta t = 7 \text{ as} = 7 \times 10^{-18} \text{ s} = 0.000 \ 000 \ 000 \ 000 \ 000 \ 007 \text{ s}$$

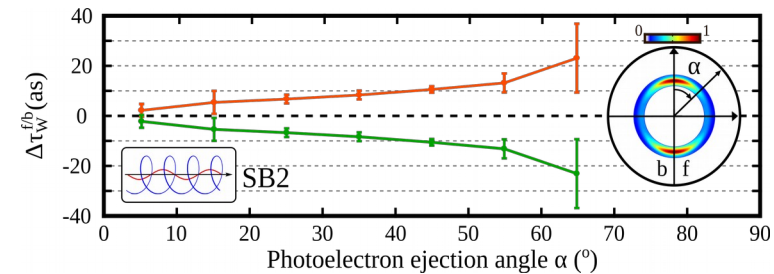
# Ultrafast meets chirality : Conclusions

Interaction between extreme light and chiral molecules allows getting previously inaccessible information about chirality, on ultrafast timescales.

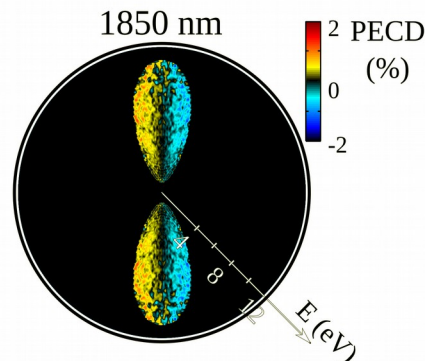
## Femtosecond pump-probe



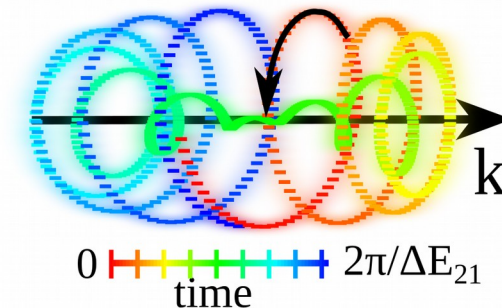
## Photoionization delays



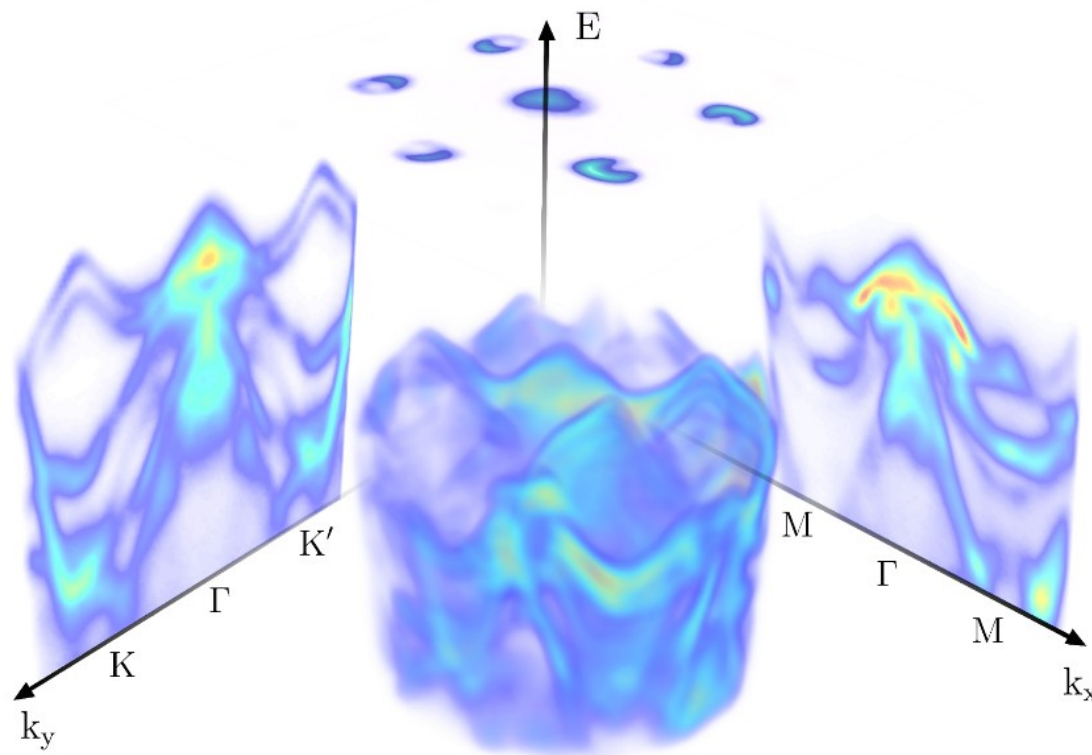
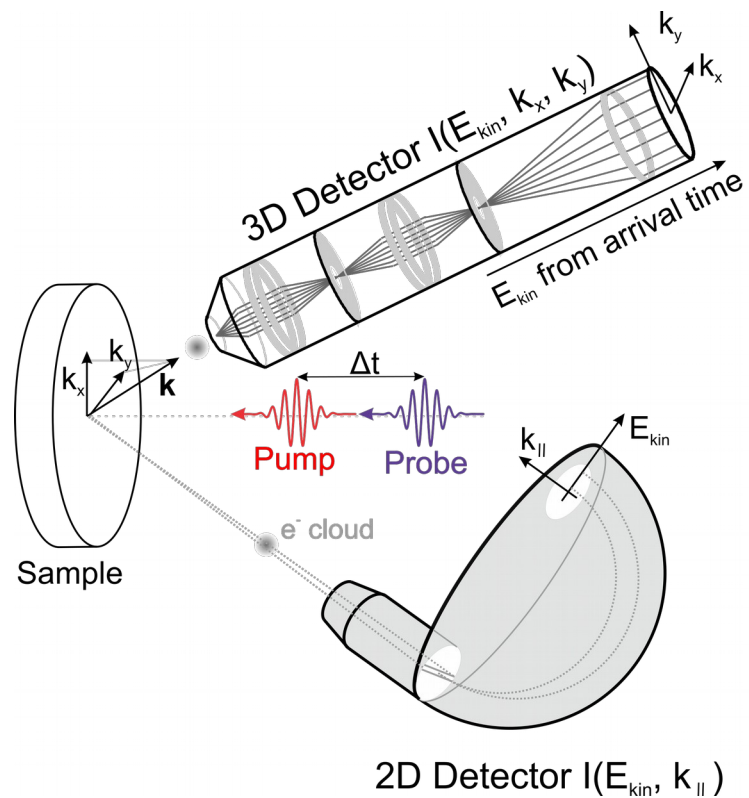
## Tunnel ionization



## Novel chiral observable : PXCD



# Now : trARPES on 2D topological materials @ FHI Berlin





# Acknowledgement



Y. Mairesse, V. Blanchet  
(UBordeaux) 2014-2018



Group of F. Légaré  
(INRS-EMT) 2012-2018



AG Ernstorfer  
(FHI Berlin) 2018-...

