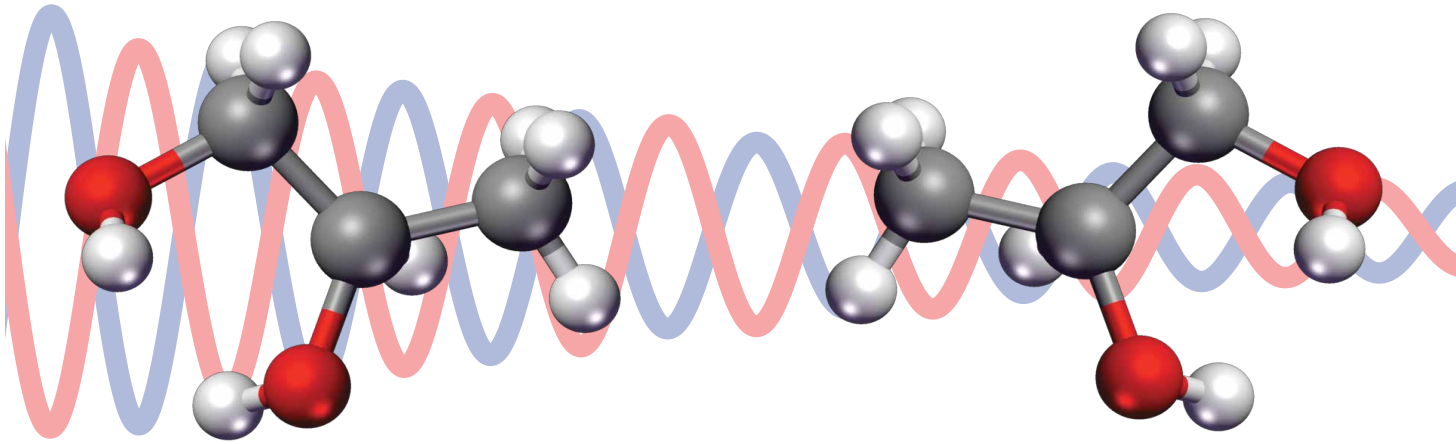
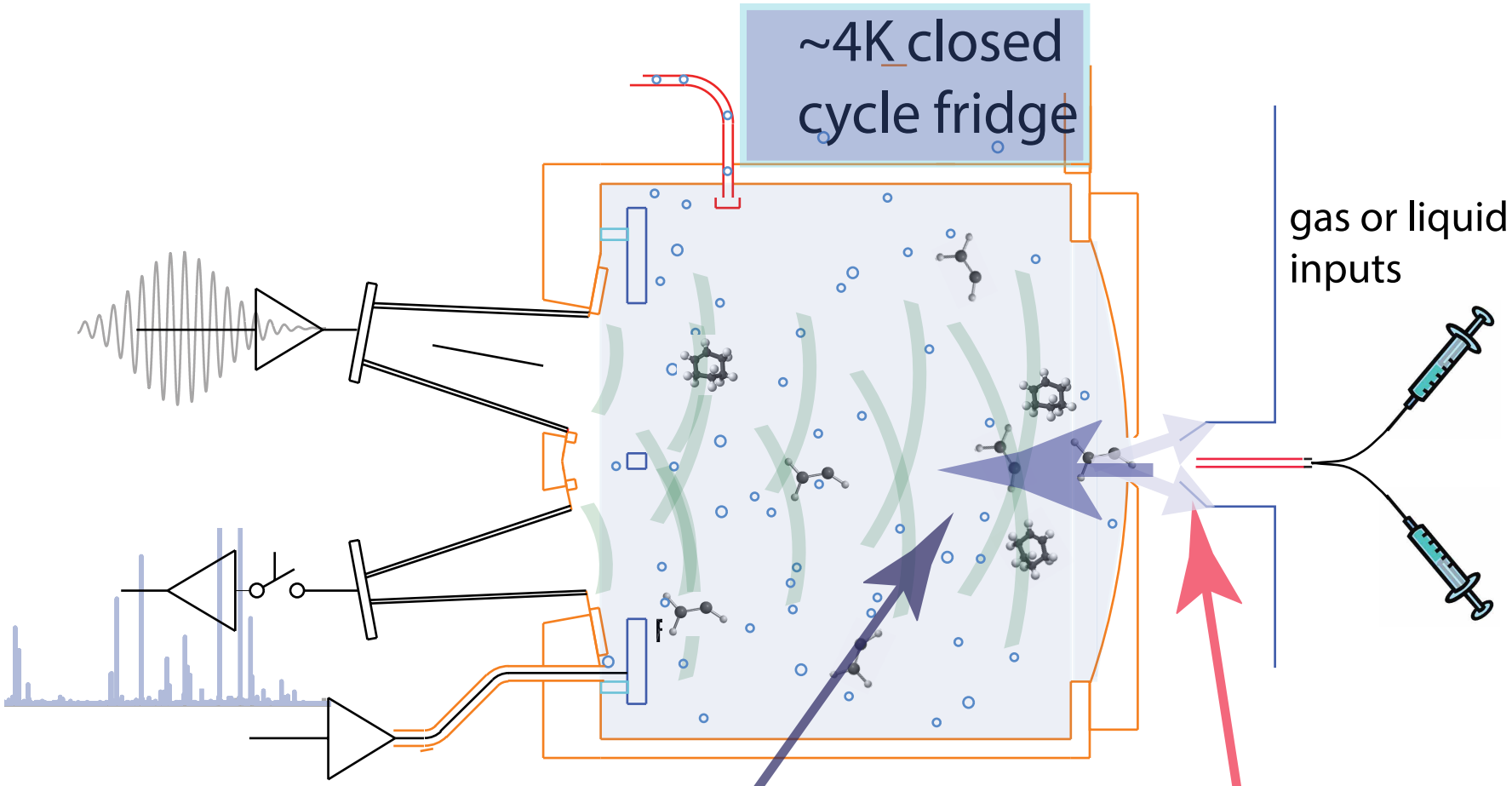
High sensitivity 1-D and 2-D spectroscopy via cryogenic buffer gas cooling

ISMS 2017
David Patterson
UCSB



Our favorite (but unusual) source of cold molecules:

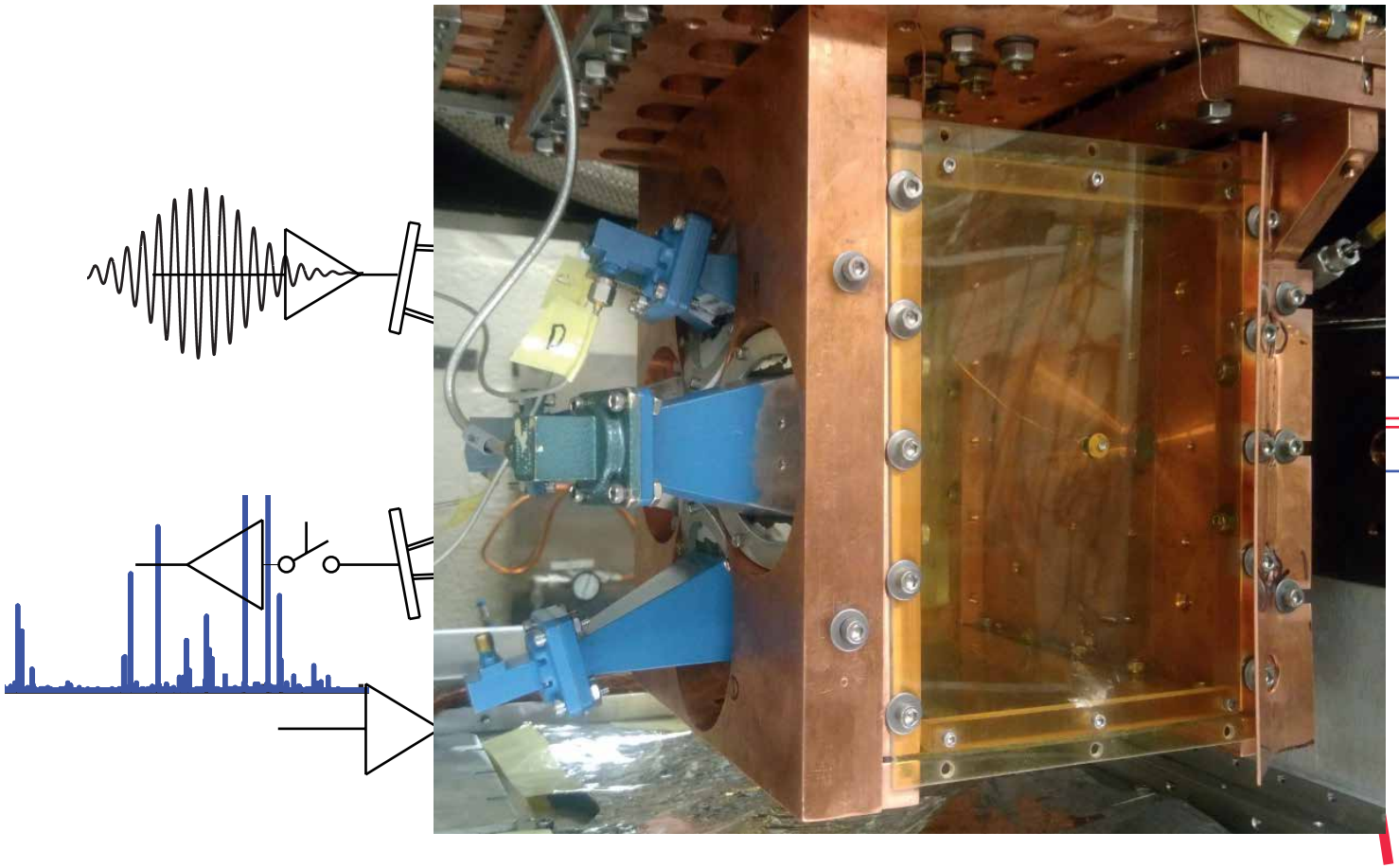


Cool (5 K, 100 msec)

Vaporize (400 K, 100 msec)

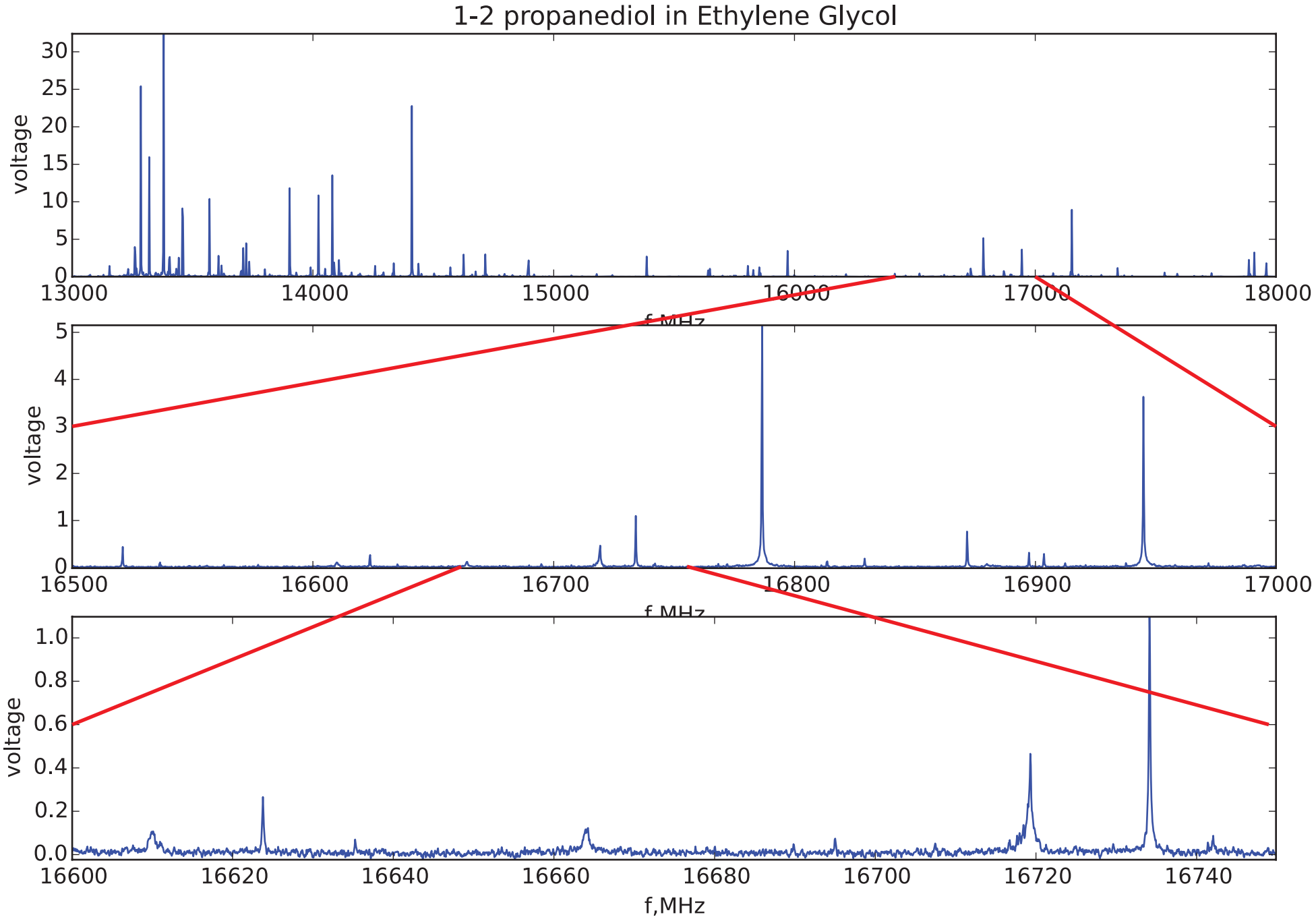
DeLucia, 1989
Doyle, 1995
Egerov, 2006
Campbell, 2008

Our favorite (but unusual) source of cold molecules:

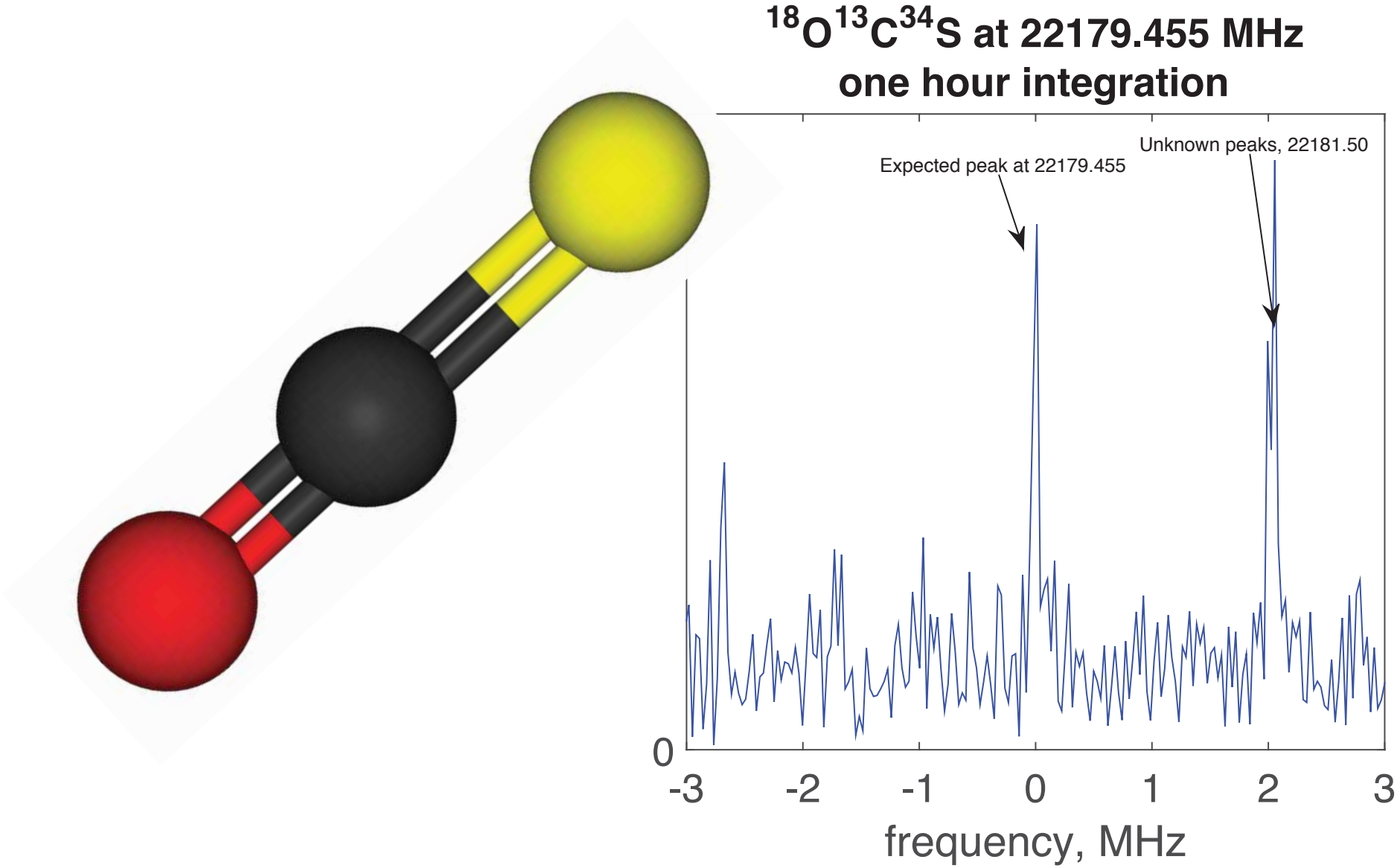


gas or liquid inputs

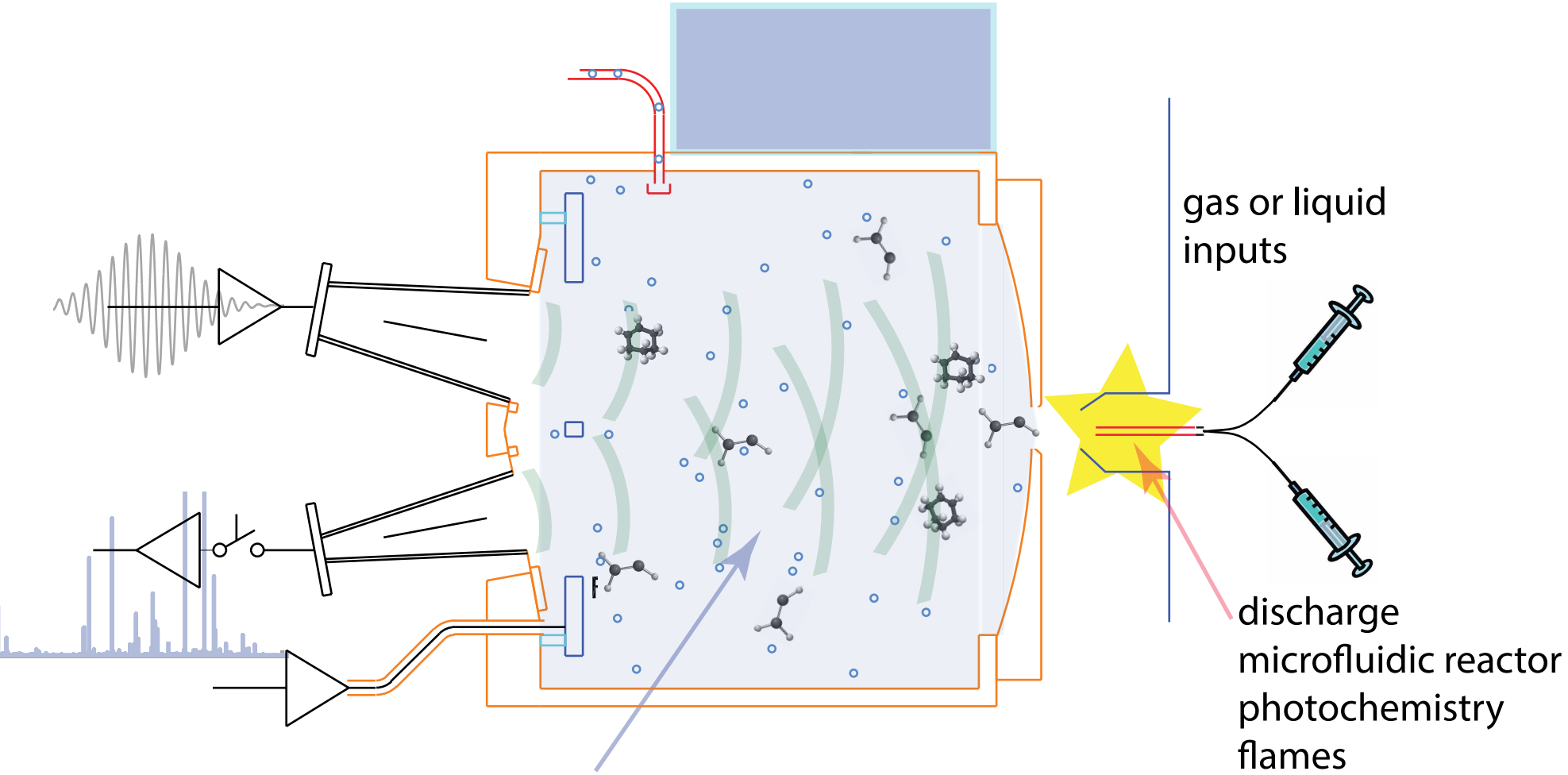
Compatible with
-neat liquids and solutions
-gas inputs
-solids (via load lock)

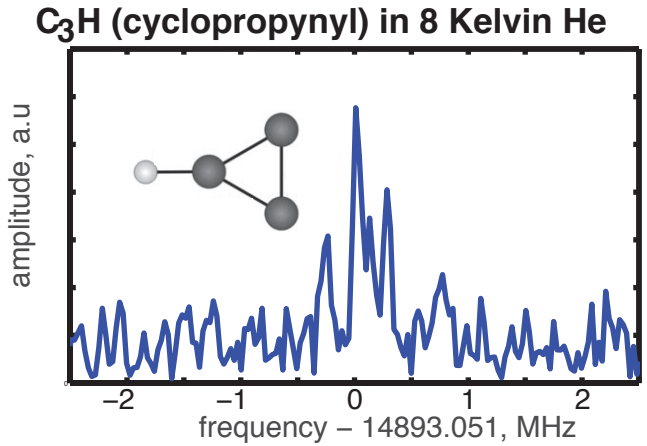

1-2 propanediol in Ethylene Glycol
voltage
f,MHz

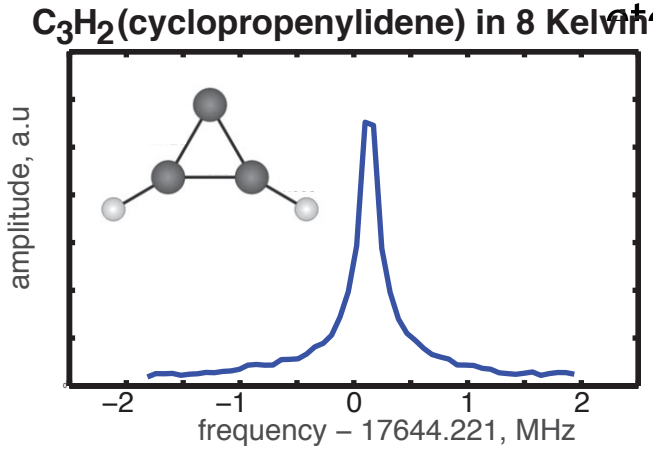
Our high repetition rate (~50 kHz) and cryogenic noise temperature give us un-precedented sensitivity



Buffer gas cooling is “gas phase matrix isolation”.

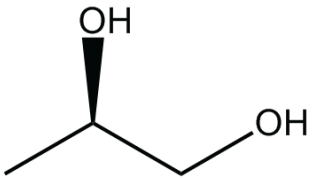


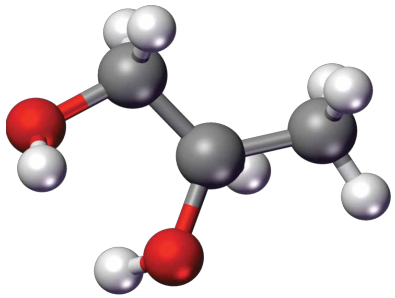


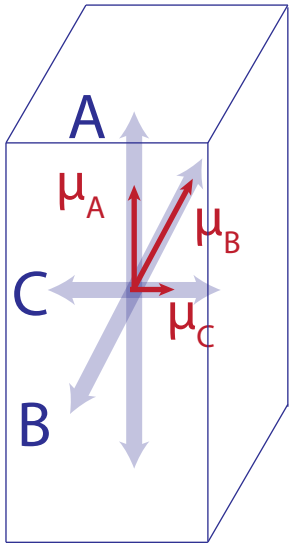


The Hamiltonian of a chiral asymmetric top is enantiomer dependent

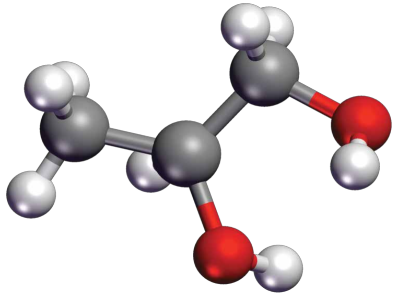
R 1,2-propanediol

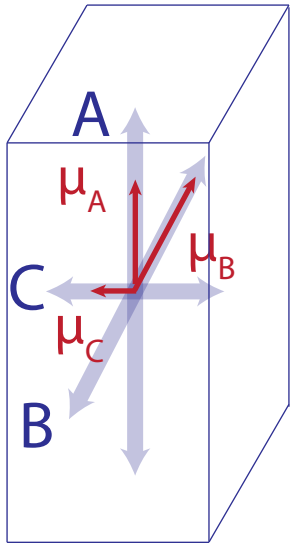


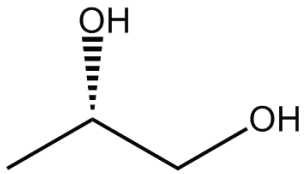




S 1,2-propanediol



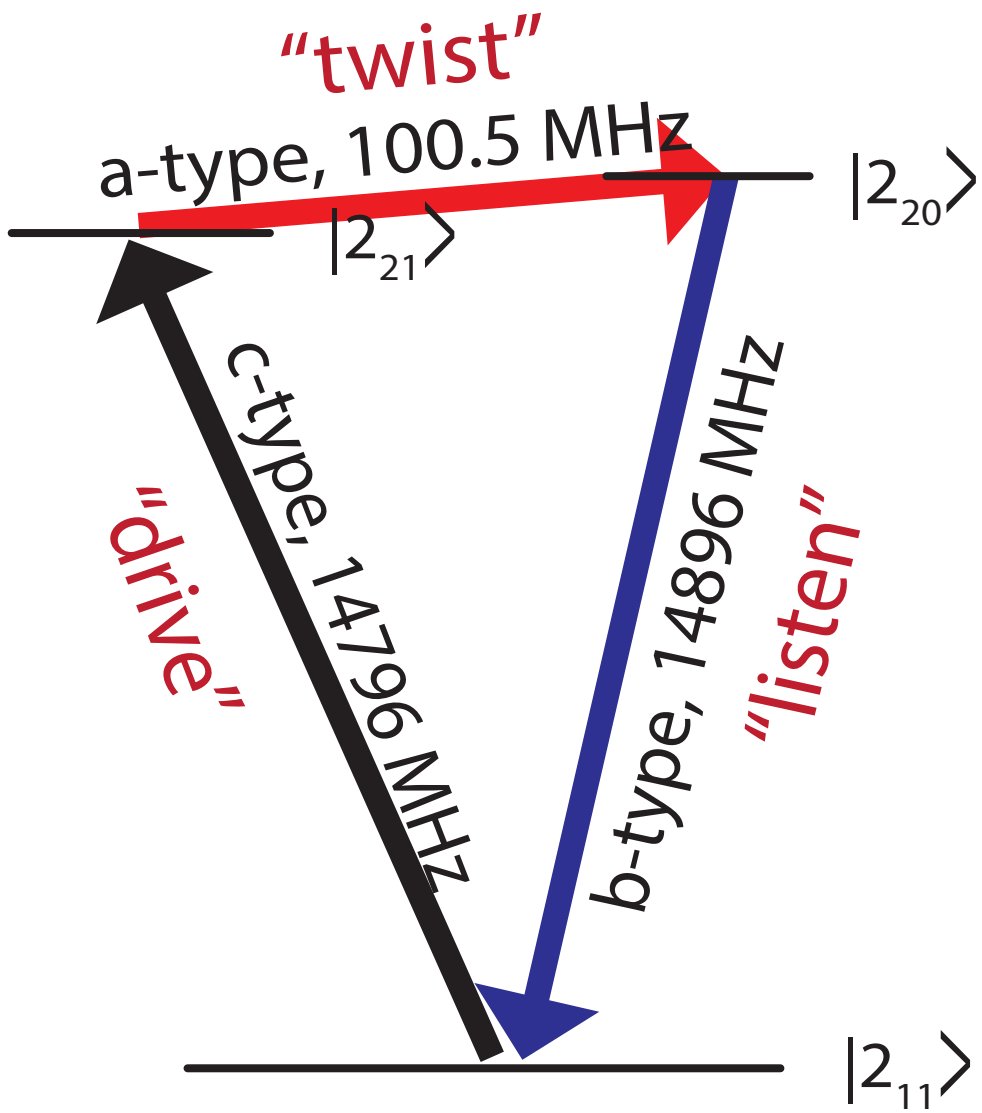


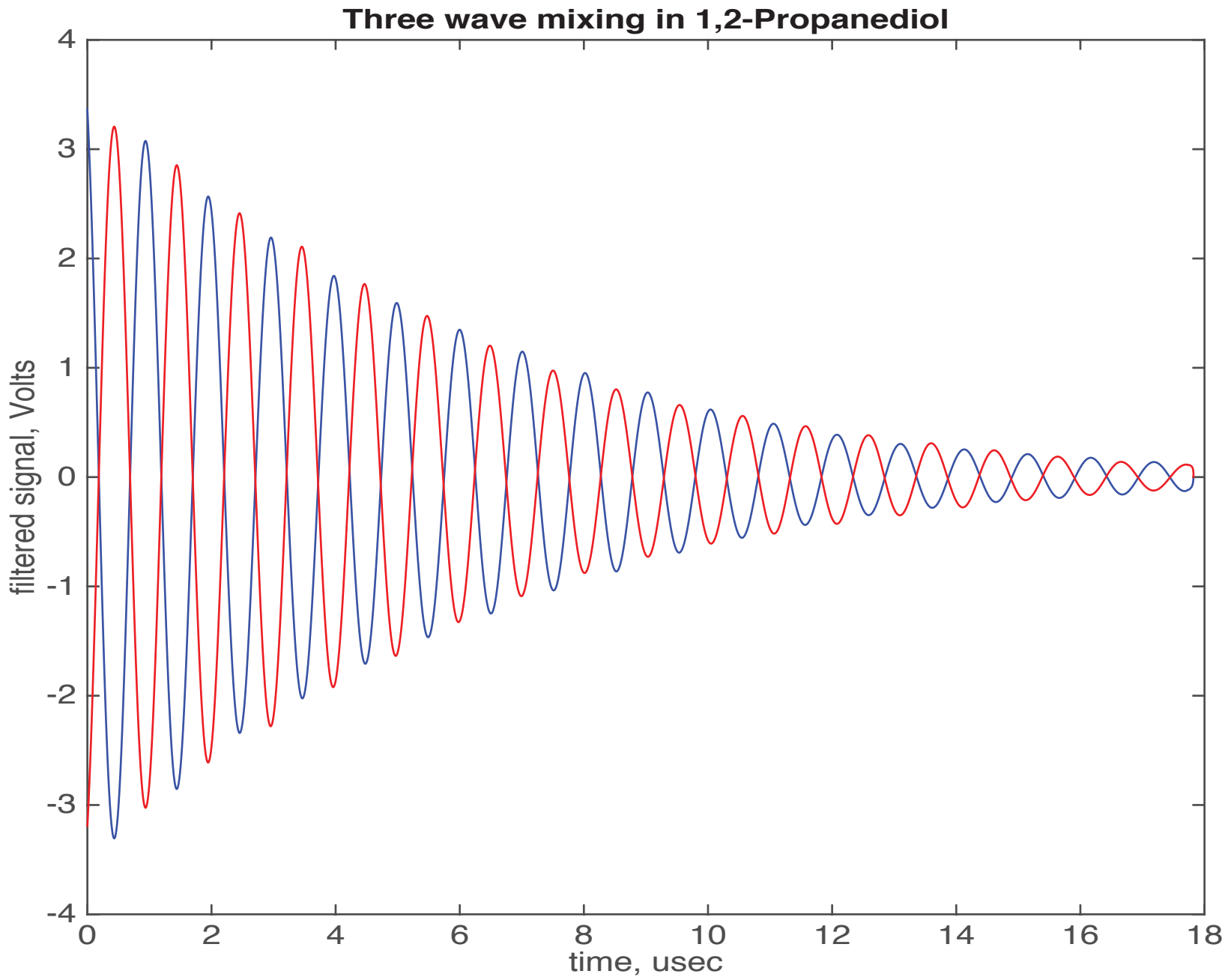


Opposite enantiomers have:
The same rotational constants A, B, and C,
The same magnitude of dipole moment components $|\mu_a|$, $|\mu_b|$, and $|\mu_c|$,
Opposite sign of the combined quantity $\mu_a\mu_b\mu_c$ (independent of choice of axes)

All rotational transitions are of a-type, b-type, or c-type,

with matrix elements proportional to μ_a, μ_b, or μ_c respectively.

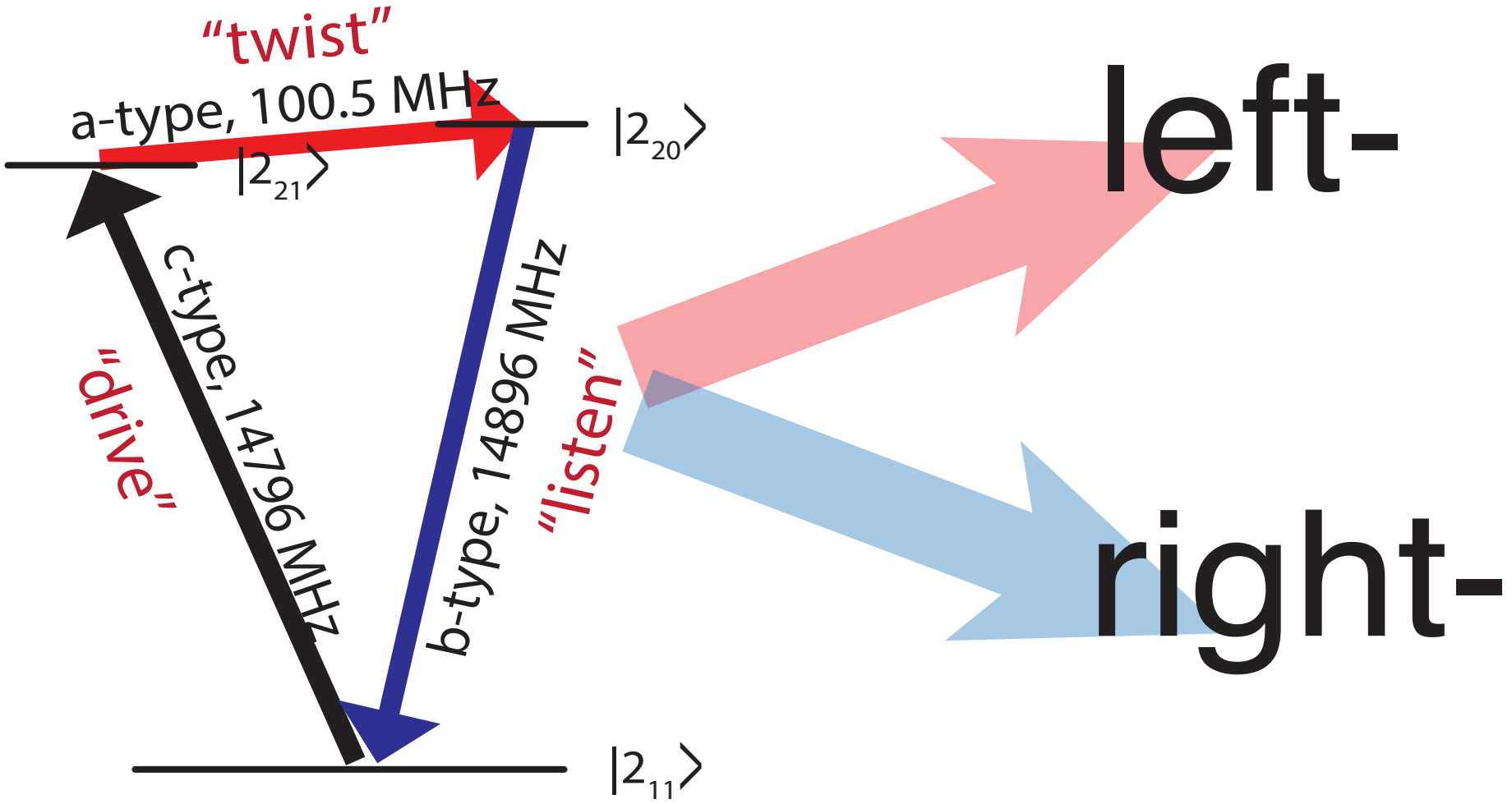




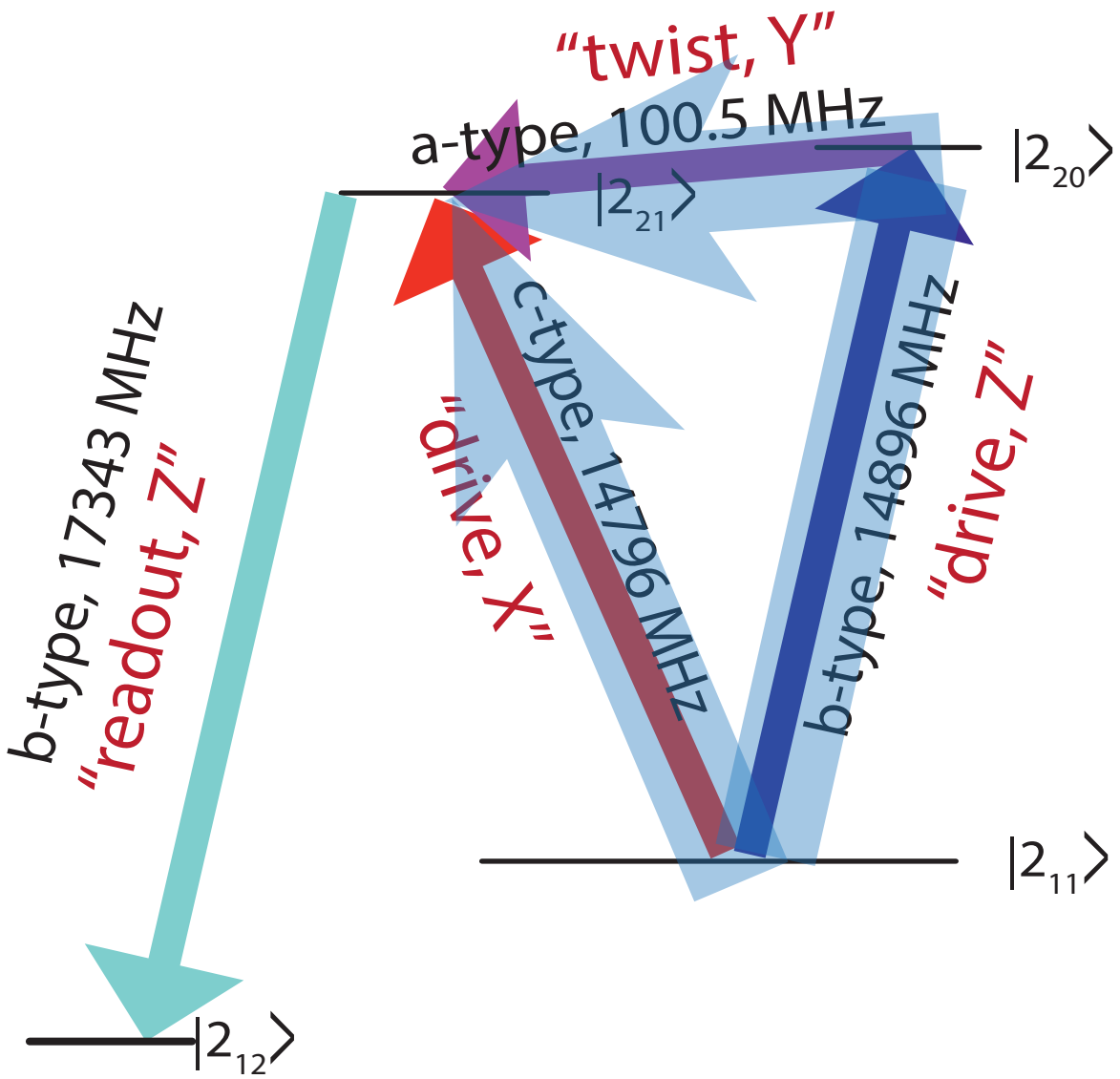
physics sensitivity is now about .0003 in one minute
..cleanliness is an issue

D. Patterson, M. Schnell, J.M. Doyle, Nature 2013
D. Patterson, J.M. Doyle, Physical Review Letters, 2013

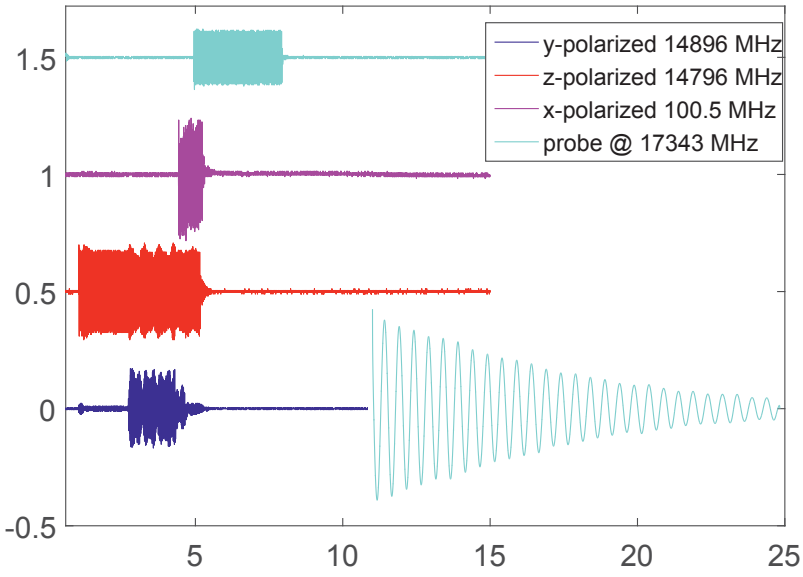
So far, we can *analyze* chiral compounds but can we separate opposite enantiomers?

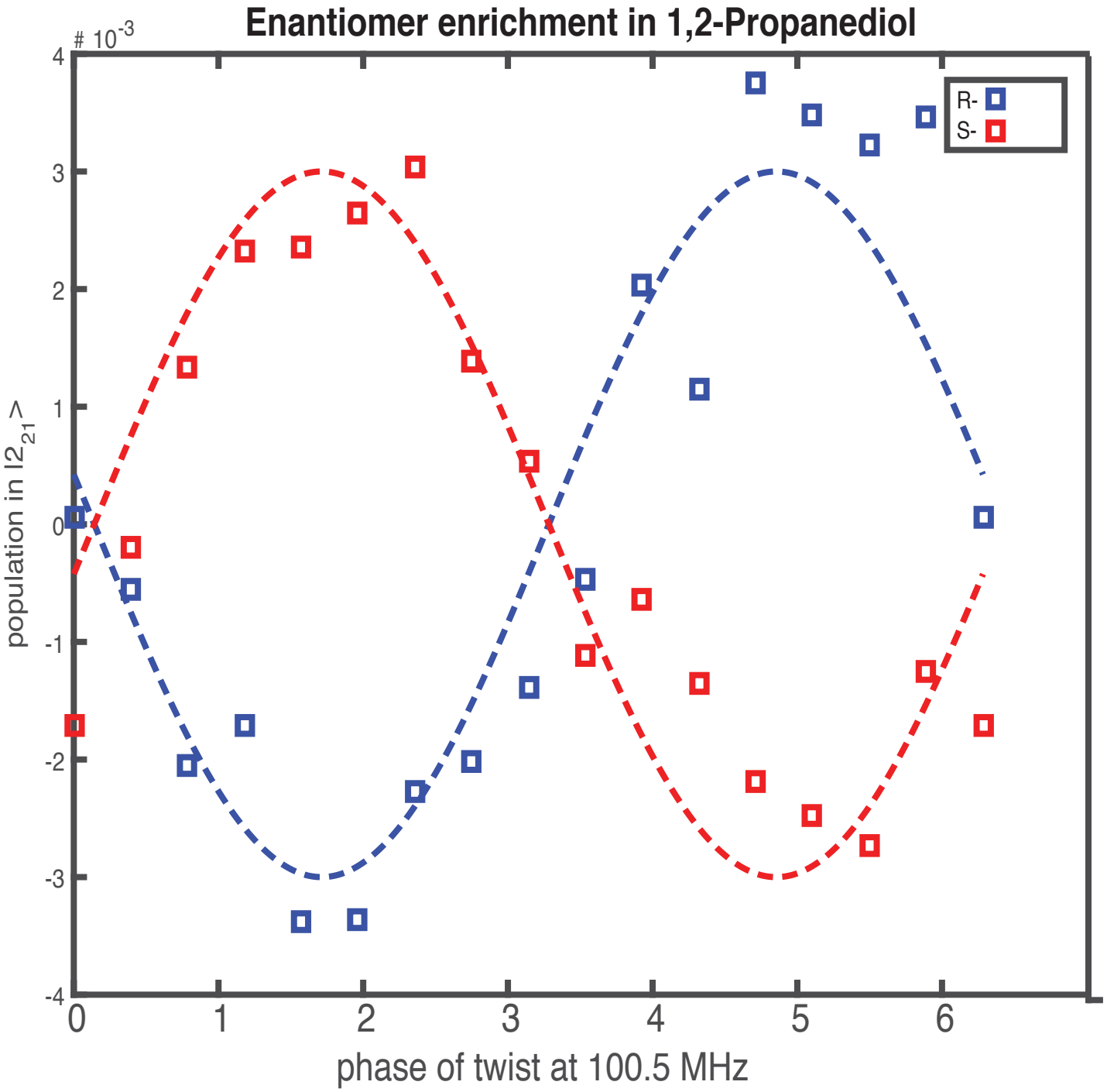


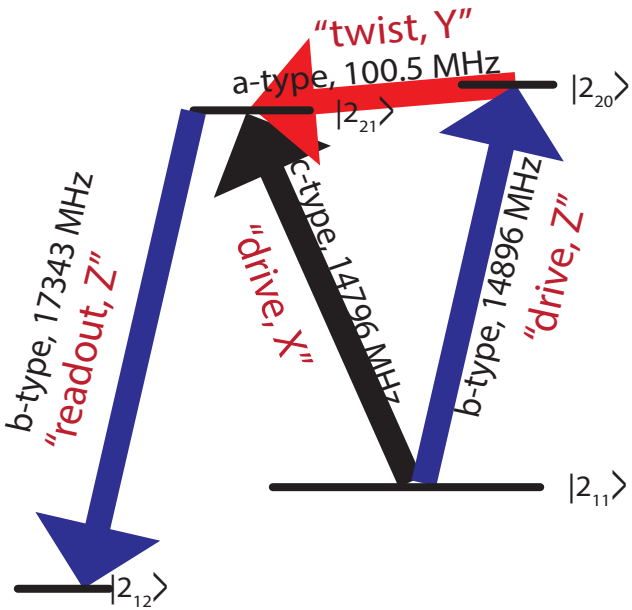
Readout with another transition



Experimental timing protocol

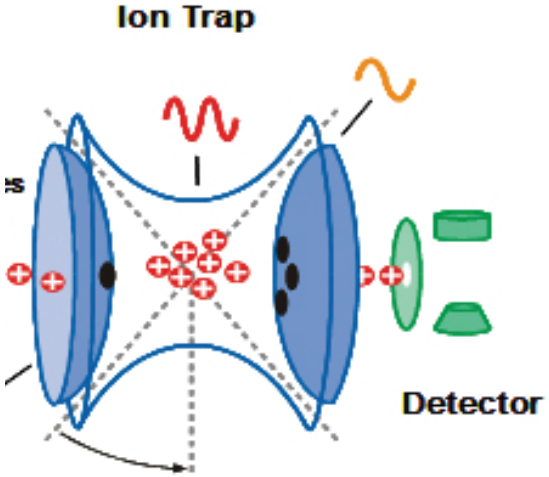




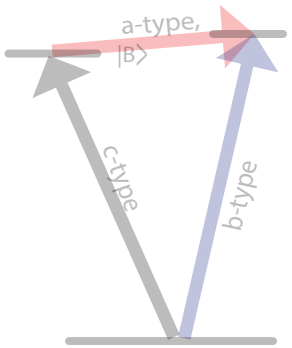


Eibenberger, Doyle, Patterson in submitted PRL

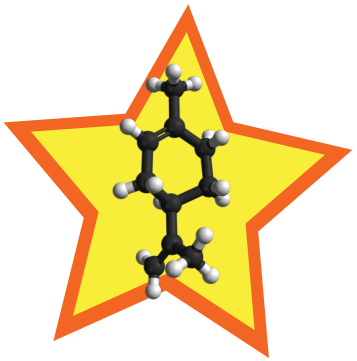
Can we retain the specificity of microwave detection, but with single molecule sensitivity?



Step 1: trap (and collisionally cool) the suspect



Step 2: selectively promote R- or S-rotationally via three wave mixing

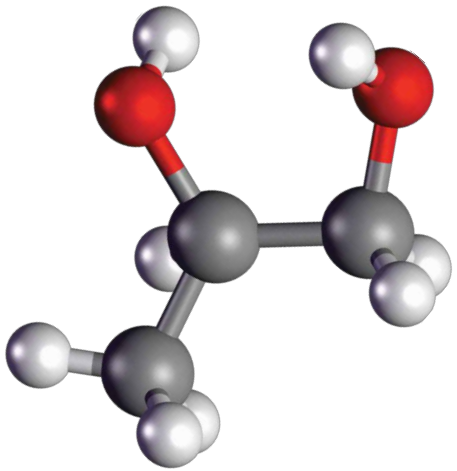


Step 3: detect in a sensitive, state-dependent way

To date we cannot prepare or read out polyatomic molecules in single quantum states

Molecules are perfect quantum machines..

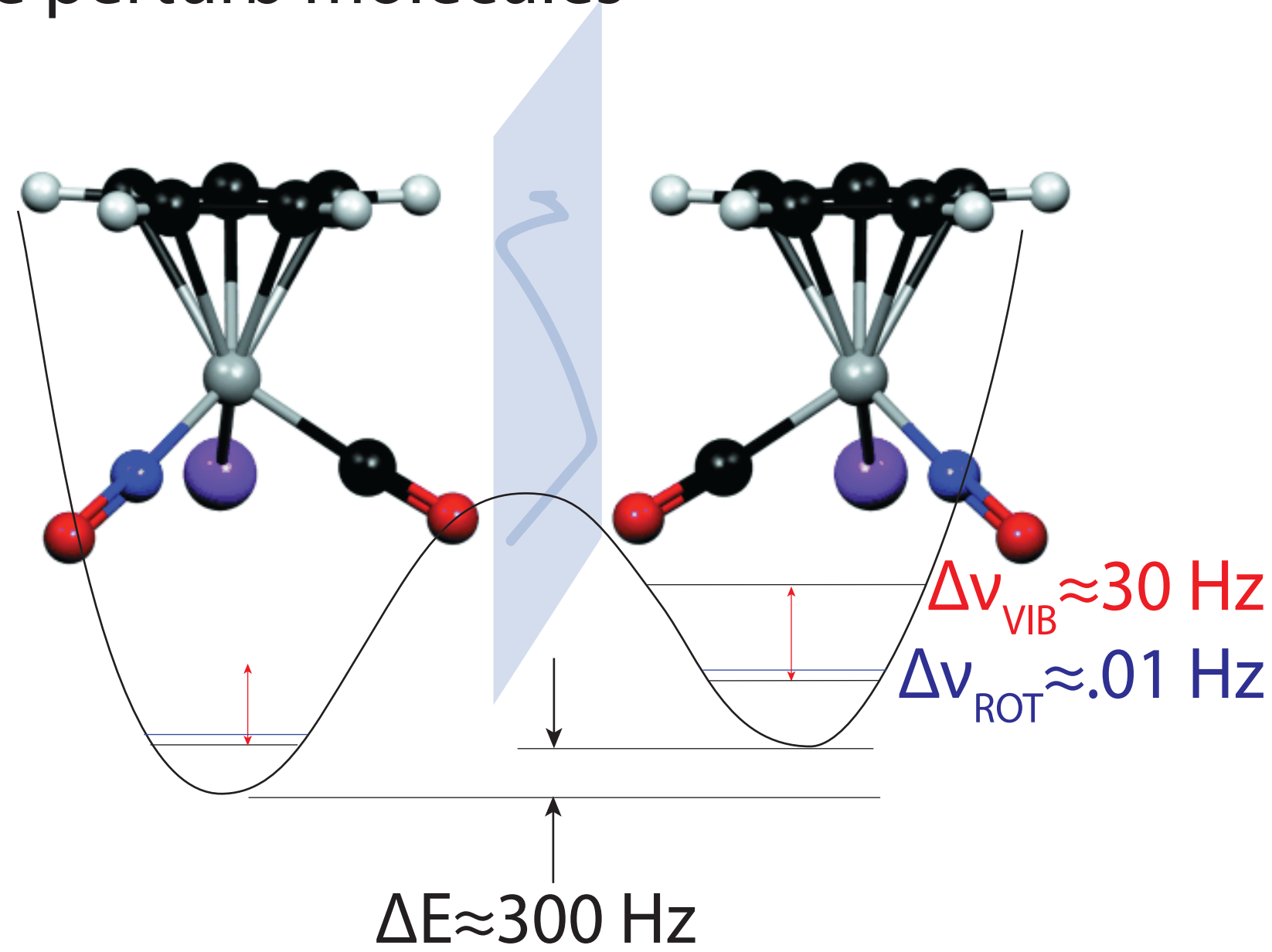
..but we treat them as if they are stuff



or

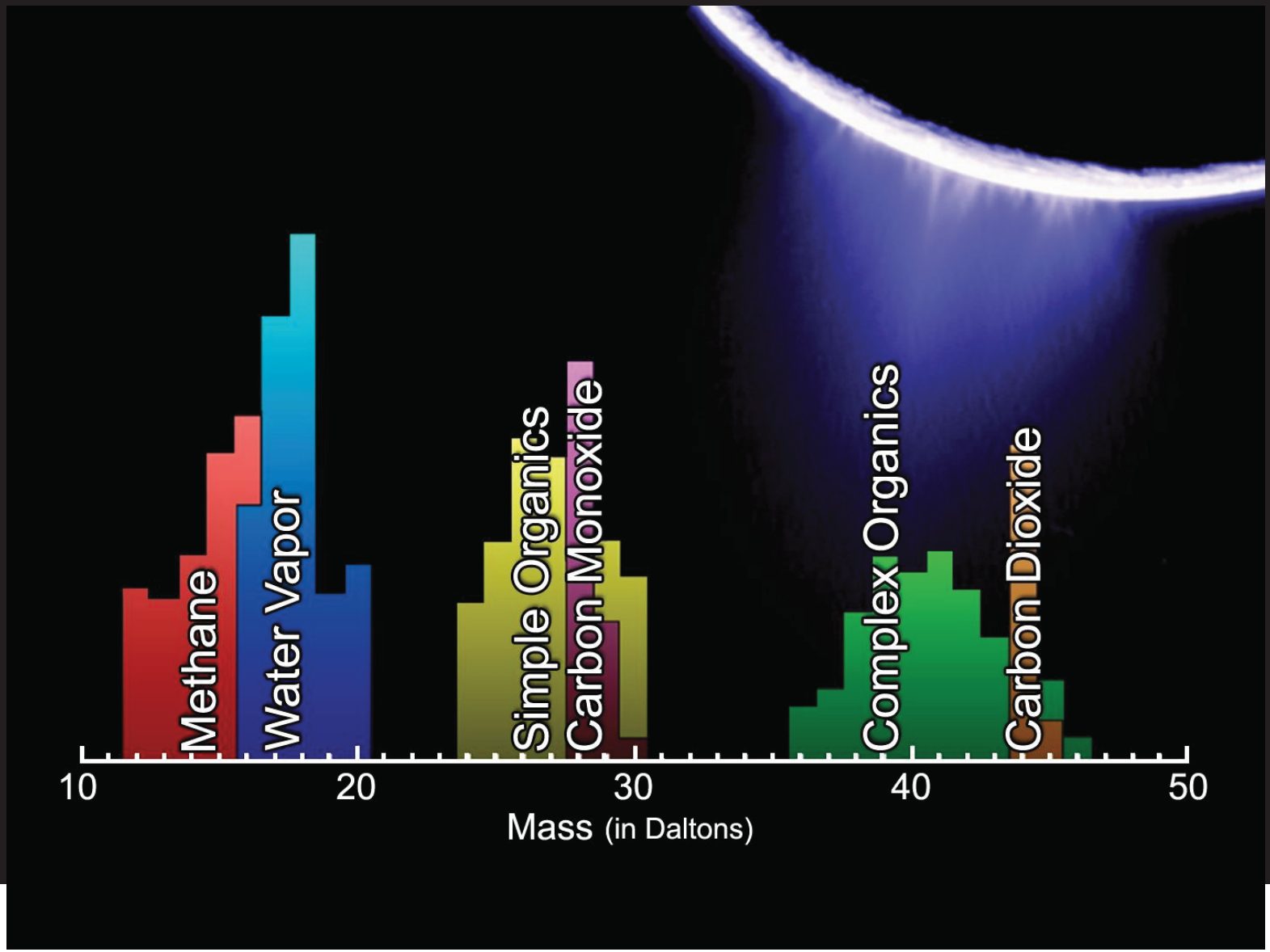
Motivation - 1

Parity violating terms from the nuclear weak force perturb molecules

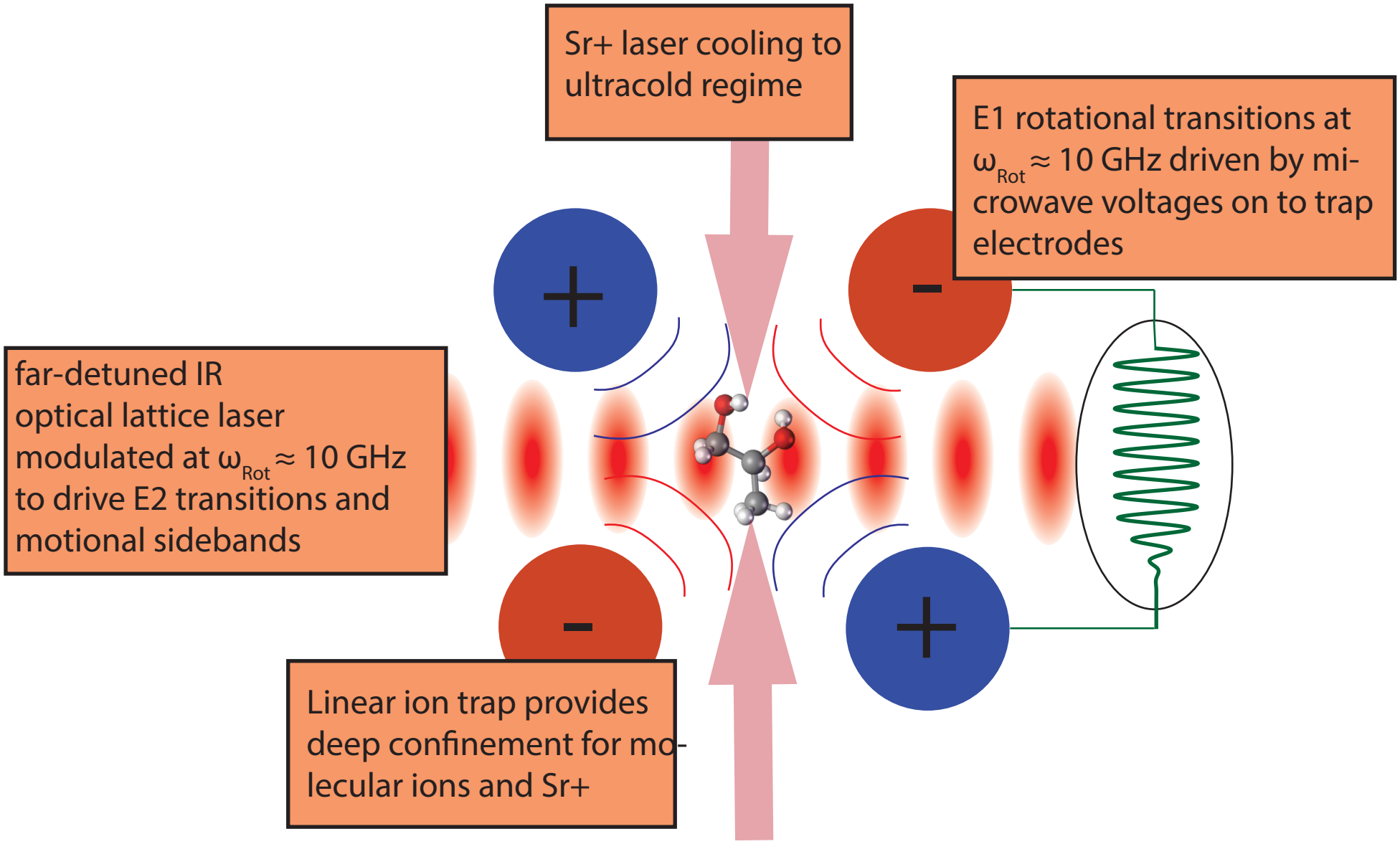


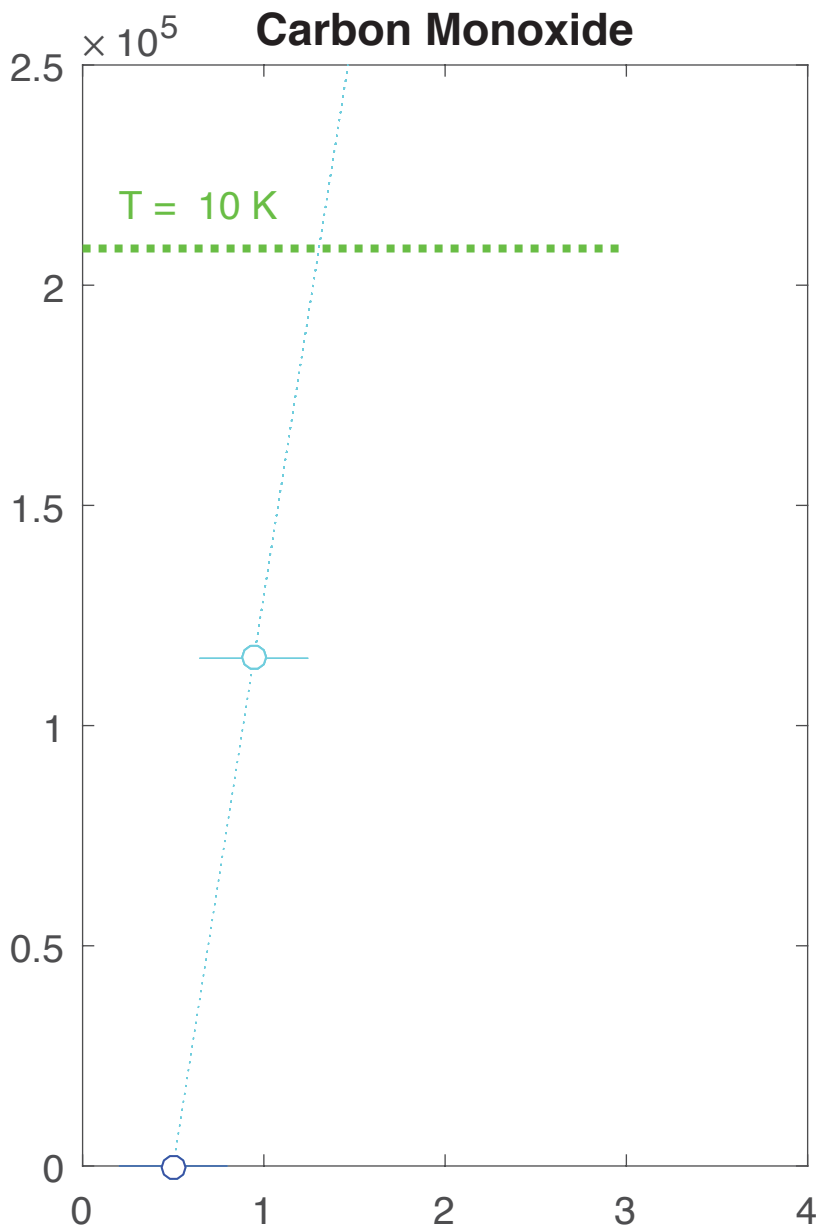
Motivation - 2

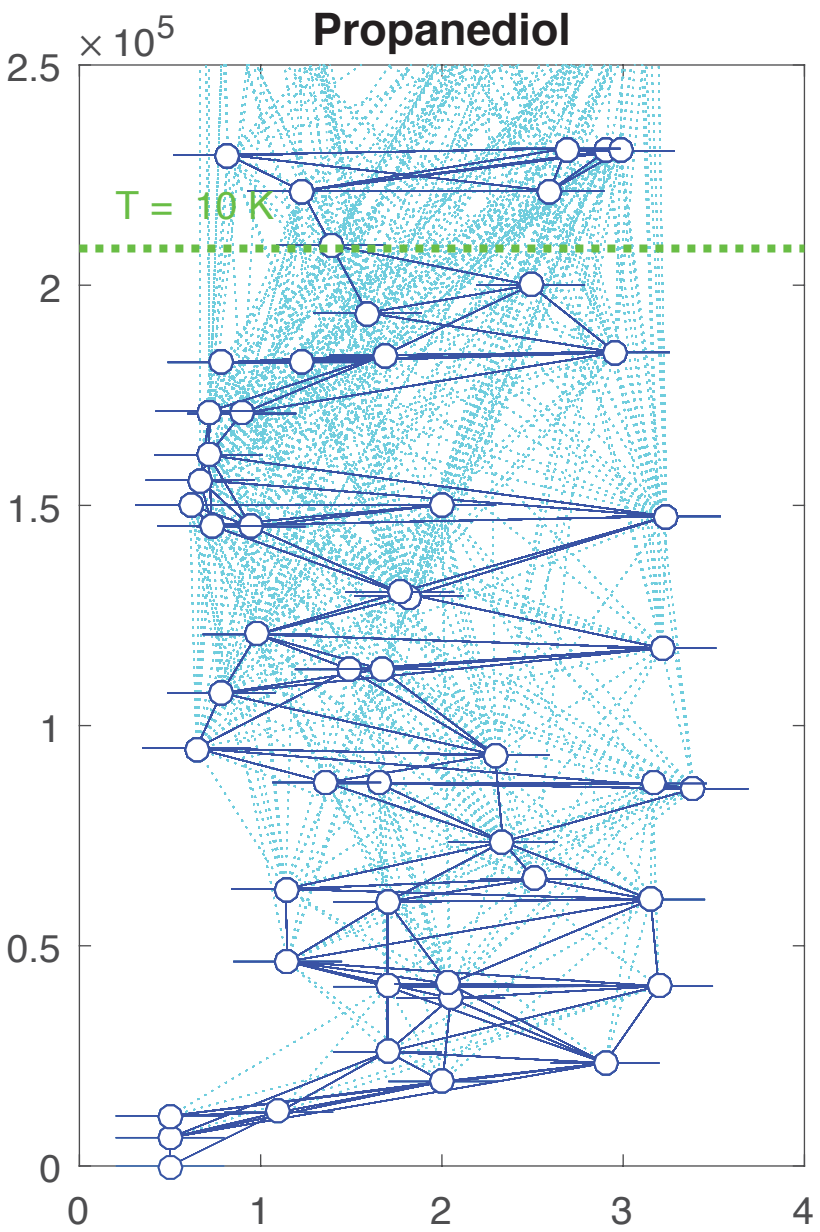
Encedalus: the most interesting mixture in the solar system?



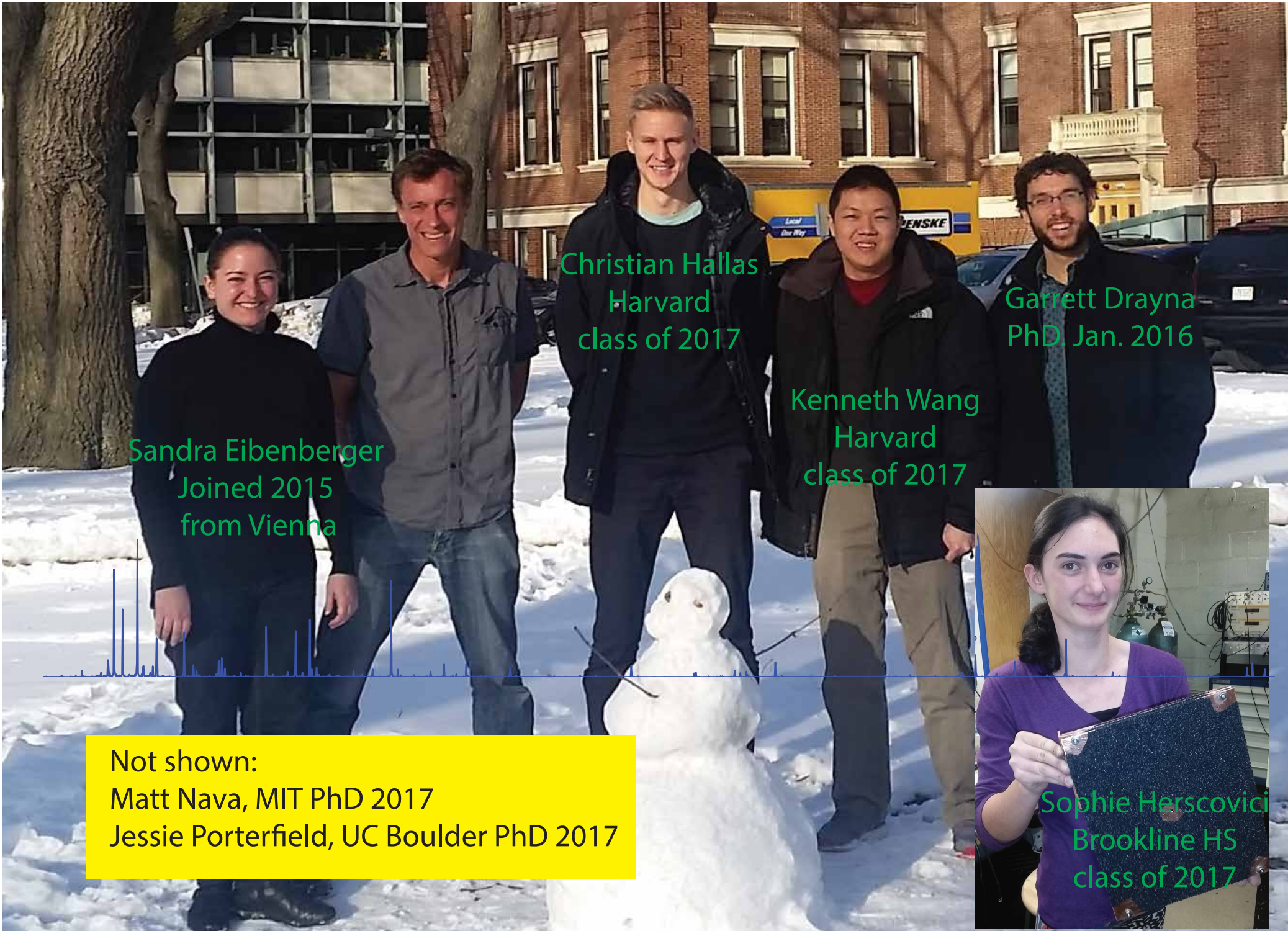
Our ongoing research at UCSB: learn to prepare manipulate, and detect molecular ions in single quantum states

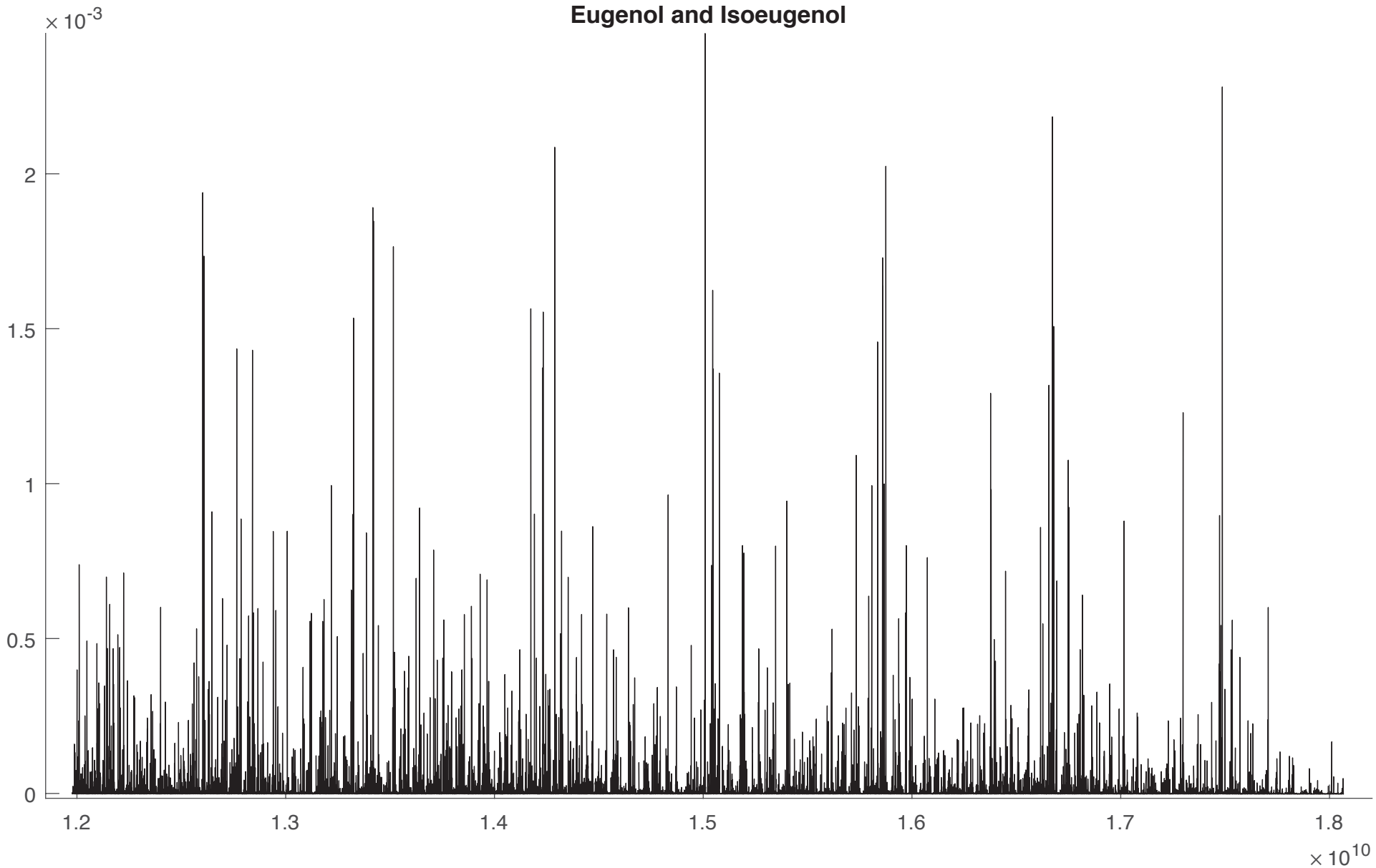



Carbon Monoxide
× 10^5
2.5
2
1.5
1
0.5
0
T = 10 K
0
1
2
3
4


Propanediol
× 10^5
2.5
2
1.5
1
0.5
0
T = 10 K
0
1
2
3
4

The postdocs and students who make this possible




Eugenol and Isoeugenol
× 10-3
2
1.5
1
0.5
0
1.2
1.3
1.4
1.5
1.6
1.7
1.8
× 1010