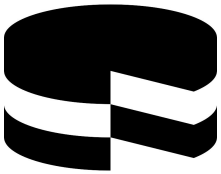
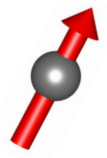
Phonons and light

infrared spectroscopy



greenhouse gases

Max Born and Edward Teller



by Alexander Tsirlin, Leipzig University

Lecture 12: November 16, 2023

Diatomic chain

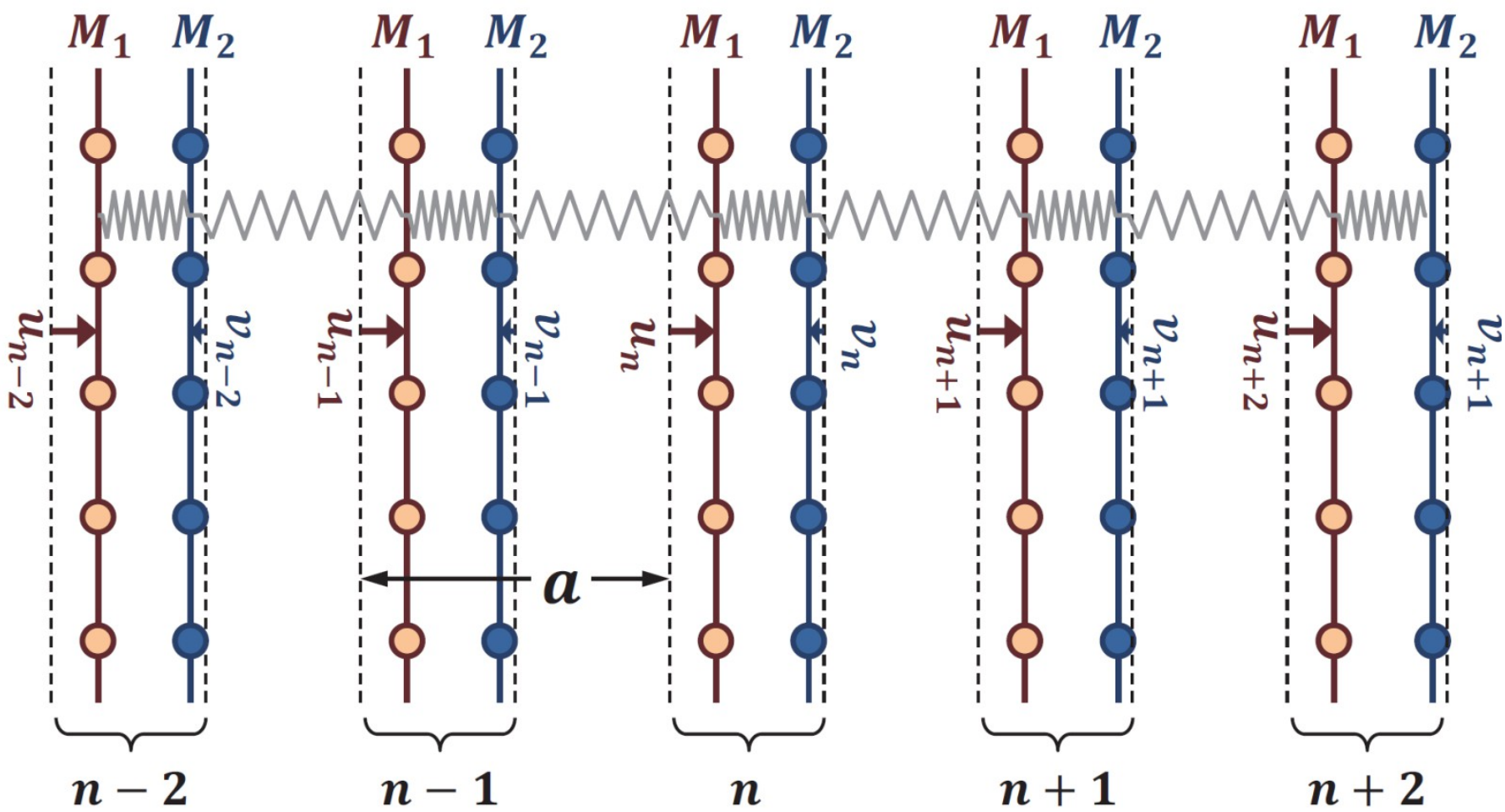


Image credit: Gross, Marx. Festkörperphysik

Acoustic vs. optical

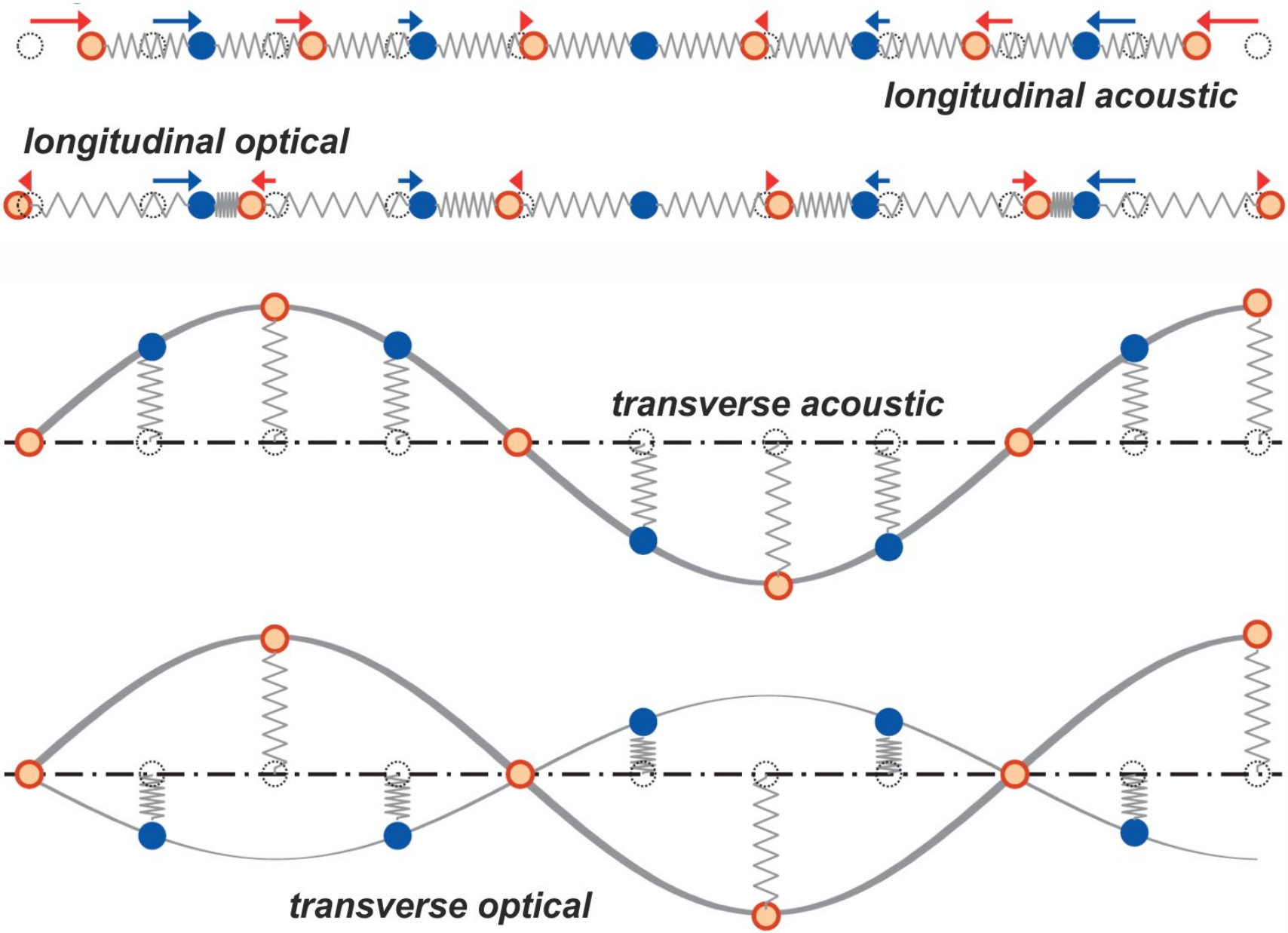


Image credit: Gross, Marx. Festkörperphysik

Person

Max Born and Edward Teller

Max Born

- 1901–06: studied physics in Wroclaw, Heidelberg, Zürich, and Göttingen (encounters with Klein, Hilbert, and Minkowski)
- 1906: PhD thesis "Stability of Elastica in a Plane and Space"
- 1910's: Berlin, Göttingen, and Frankfurt; special relativity and lattice dynamics;

  There is no other Born to be found in Germany today (Einstein)
- 1921-33: professor in Göttingen matrix representation of quantum mechanics (together with Heisenberg)
- from 1936: professor in Edinburgh
- 1954: Nobel Prize in Physics "for his fundamental research in quantum mechanics"

Max Born
1882–1970

Max Born

- 1901–06: studied physics in Wroclaw, Heidelberg, Zürich, and Göttingen (encounters with Klein, Hilbert, and Minkowski)
- 1906: PhD thesis "Stability of Elastica in a Plane and Space"
- 1910's: Berlin, Göttingen, and Frankfurt; special relativity and lattice dynamics;
  There is no other Born to be found in Germany today (Einstein)
- 1921-33: professor in Göttingen matrix representation of quantum mechanics (together with Heisenberg)
- from 1936: professor in Edinburgh
- 1954: Nobel Prize in Physics "for his fundamental research in quantum mechanics"

Max Born
1882–1970

Max Born

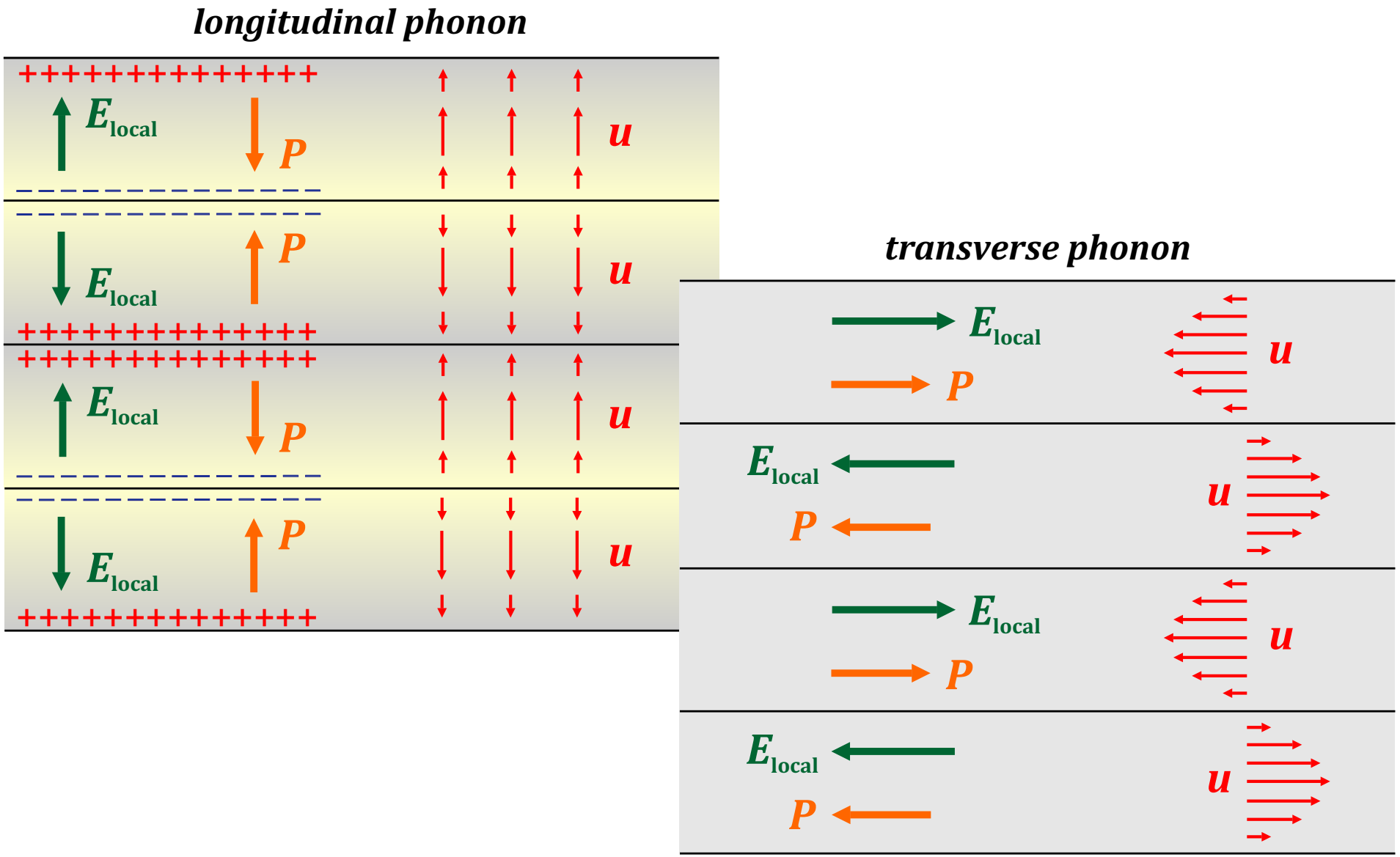
- 1901–06: studied physics in Wroclaw, Heidelberg, Zürich, and Göttingen (encounters with Klein, Hilbert, and Minkowski)
- 1906: PhD thesis "Stability of Elastica in a Plane and Space"
- 1910's: Berlin, Göttingen, and Frankfurt; special relativity and lattice dynamics;
  There is no other Born to be found in Germany today (Einstein)
- 1921-33: professor in Göttingen matrix representation of quantum mechanics (together with Heisenberg)
- from 1936: professor in Edinburgh
- 1954: Nobel Prize in Physics "for his fundamental research in quantum mechanics"

Max Born
1882–1970

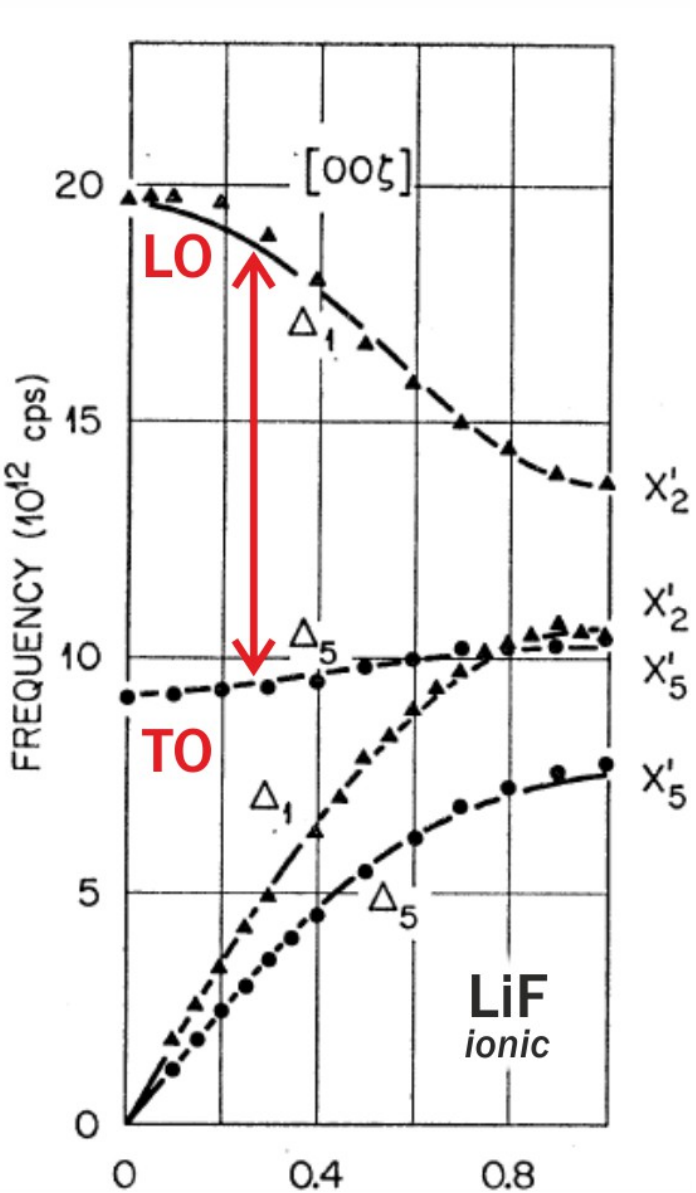
- 1901–06: studied physics in Wroclaw, Heidelberg, Zürich, and Göttingen (encounters with Klein, Hilbert, and Minkowski)
- 1906: PhD the "Stability of El
- 1910's: Berlin, special relativi
  There is no ot in Germany to
- 1921-33: profe matrix represe (together with
- from 1936: pro
- 1954: Nobel P fundamental r

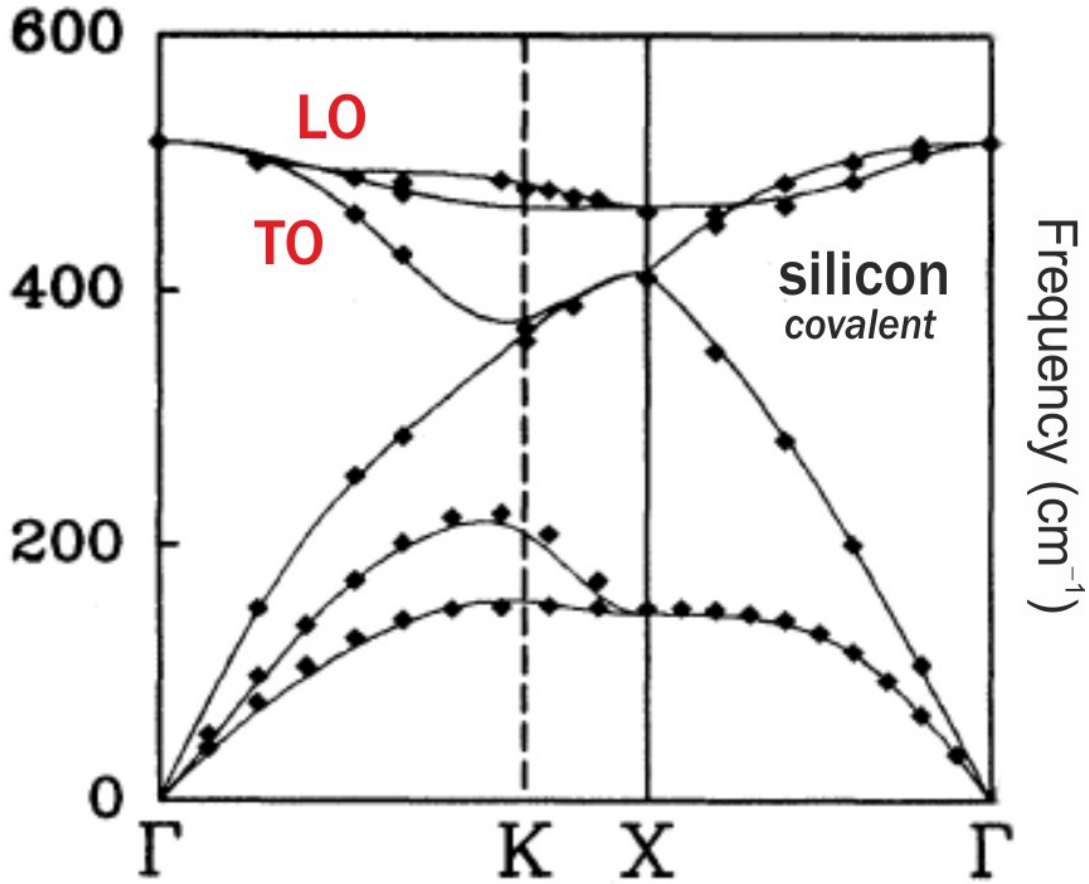
Max Born
1882–1970

Image credit: Julian Herzog (CC-BY-SA)


longitudinal phonon
E_{local}
P
u
transverse phonon
E_{local}
P
u

LO-TO splitting





Phys. Rev. 168, 970 (1968) and Phys. Rev. B 43, 7231 (1991)

Edward Teller

Edward Teller
1908–2003

- 1927–28: studied in Munich with Sommerfeld
- 1929–30: PhD in Leipzig with Heisenberg
- 1931–33: Max Born's assistant in Göttingen
- 1934: emigrates to England, then to US

  Jahn-Teller effect, BET absorption isotherm

Edward Teller

Edward Teller
1908–2003

- 1927–28: studied in Munich with Sommerfeld
- 1929–30: PhD in Leipzig with Heisenberg
- 1931–33: Max Born's assistant in Göttingen
- 1934: emigrates to England, then to US
  Jahn-Teller effect, BET absorption isotherm
- 1942–45: Manhattan project (nuclear bomb)
- 1951: working design of the hydrogen bomb

Edward Teller

Edward Teller
1908–2003

- 1927–28: studied in Munich with Sommerfeld
- 1929–30: PhD in Leipzig with Heisenberg
- 1931–33: Max Born's assistant in Göttingen
- 1934: emigrates to England, then to US
  Jahn-Teller effect, BET absorption isotherm
- 1942–45: Manhattan project (nuclear bomb)
- 1951: working design of the hydrogen bomb

1991 Ig Nobel Prize for Peace
for his *lifelong efforts to change the meaning of Peace as we know it*

Edward Teller

Edward Teller
1908–2003

- 1927–28: studied in Munich with Sommerfeld
- 1929–30: PhD in Leipzig with Heisenberg
- 1931–33: Max Born's assistant in Göttingen
- 1934: emigrates to England, then to US
  Jahn-Teller effect, BET absorption isotherm
- 1942–45: Manhattan project (nuclear bomb)
- 1951: working design of the hydrogen bomb

1991 Ig Nobel Prize for Peace
for his *lifelong efforts to change the meaning of Peace as we know it*

Edward is full of enthusiasm about these possibilities; this is perhaps an indication they will not work (S. Ulam)

Edward Teller

Edward Teller
1908–2003

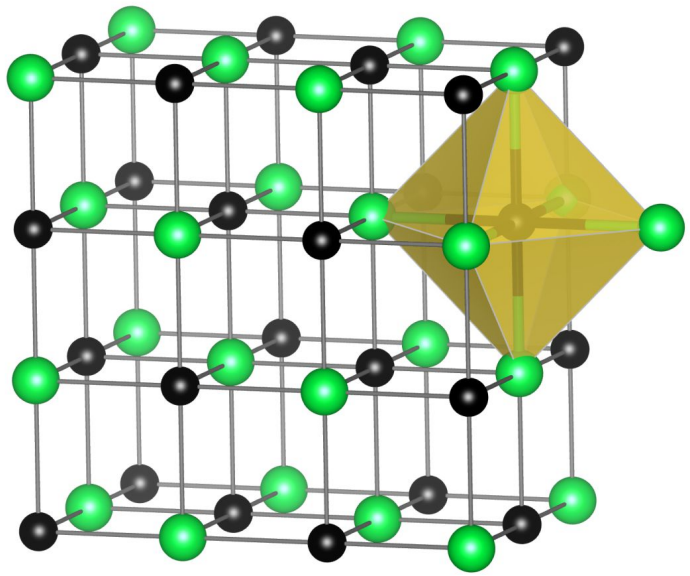
- 1927–28: studied in Munich with Sommerfeld
- 1929–30: PhD in Leipzig with Heisenberg
- 1931–33: Max Born's assistant in Göttingen
- 1934: emigrates to England, then to US
  Jahn-Teller effect, BET absorption isotherm
- 1942–45: Manhattan project (nuclear bomb)
- 1951: working design of the hydrogen bomb

1991 Ig Nobel Prize for Peace
for his *lifelong efforts to change the meaning of Peace as we know it*

Edward is full of enthusiasm about these possibilities; this is perhaps an indication they will not work (S. Ulam)

It would have been a better world without Teller (I. Rabi)

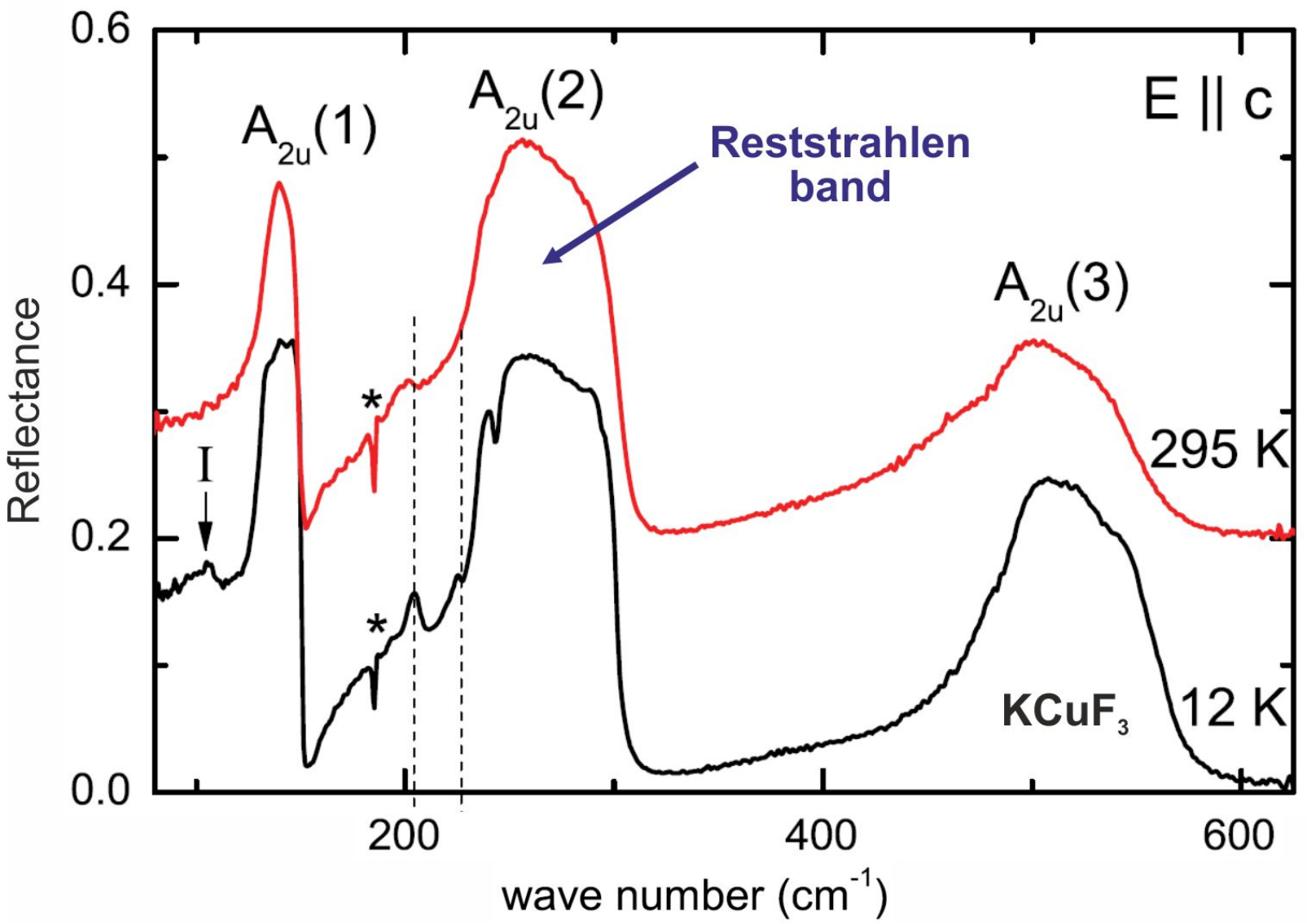
	r_0 (Å)	T_m (K)	E_{lat} (eV)	ω_{LO} / ω_{TO} (THz)	$\varepsilon_{\mathrm{st}}$
NaF	2.32	1269	9.43	81.6 / 49.9	5.1
NaCl	2.82	1074	7.97	51.3 / 34.1	5.9
NaBr	2.99	1020	7.59	40.7 / 27.4	6.4
NaI	3.24	933	7.07	34.1 / 22.9	7.3



$$E = -\frac{\alpha e^2}{4\pi\varepsilon_0 r_0}\left(1 - \frac{1}{m}\right)$$

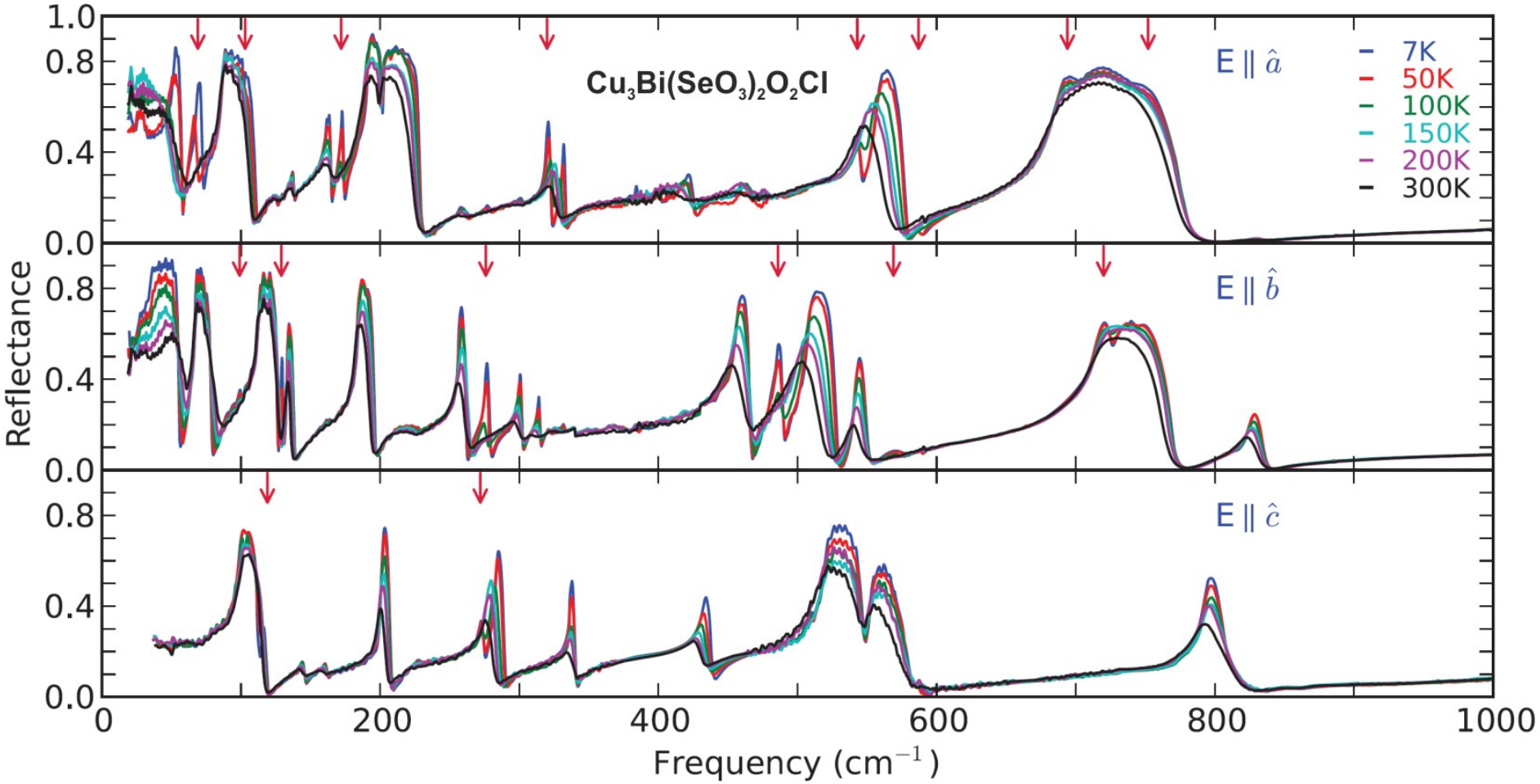
Data from CRC Handbook of Chemistry and Physics

Spectrum of optical phonons

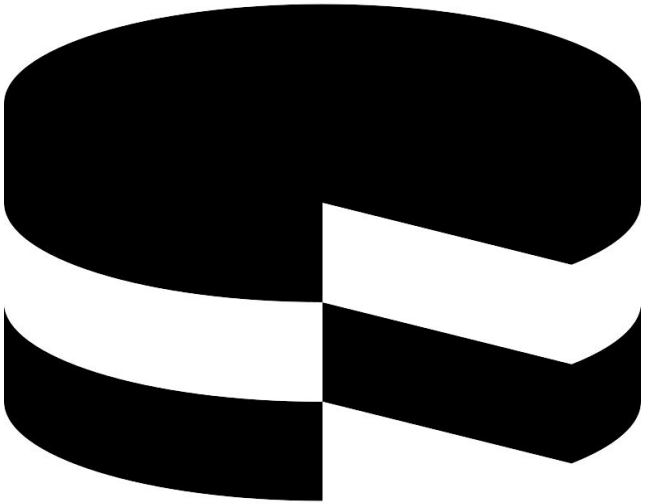


Ann. Phys. (Berlin) 523, 645 (2011)

Spectrum of optical phonons



Phys. Rev. B 86, 174104 (2012)



Material

greenhouse gases

Earth's heat balance

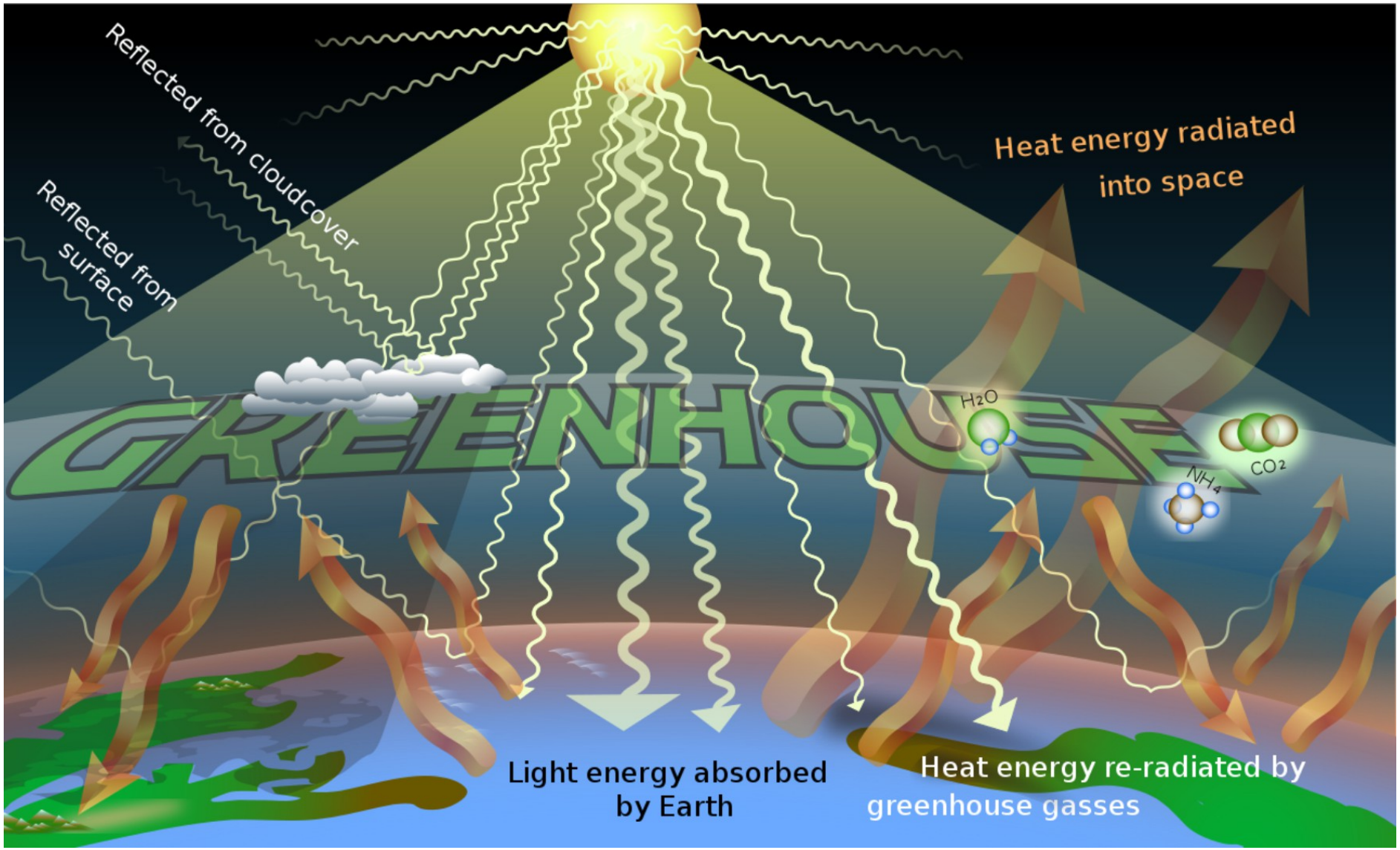


Image credit: A loose necktie (CC-BY-SA)

Greenhouse gases

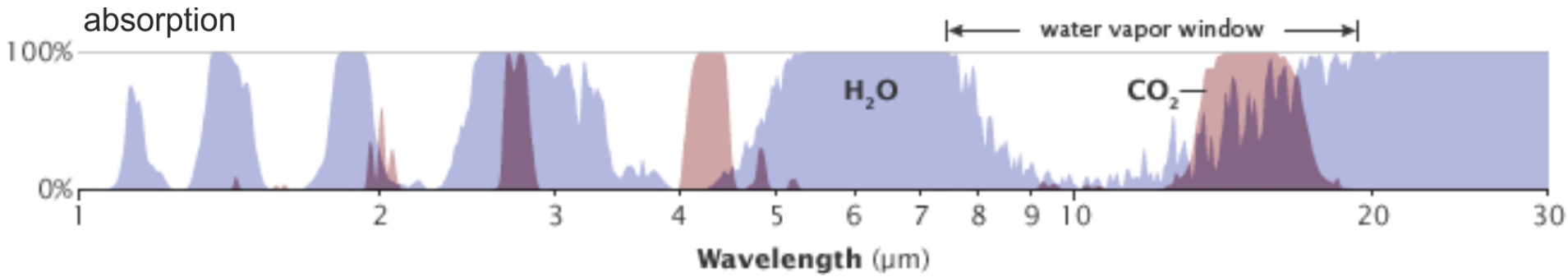
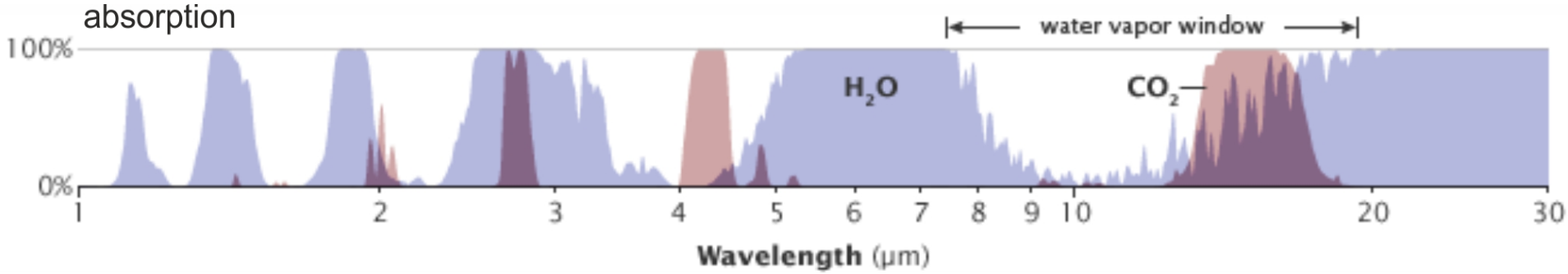


Image credits: NASA (public domain) and Delorme (CC-BY-SA)

Greenhouse gases



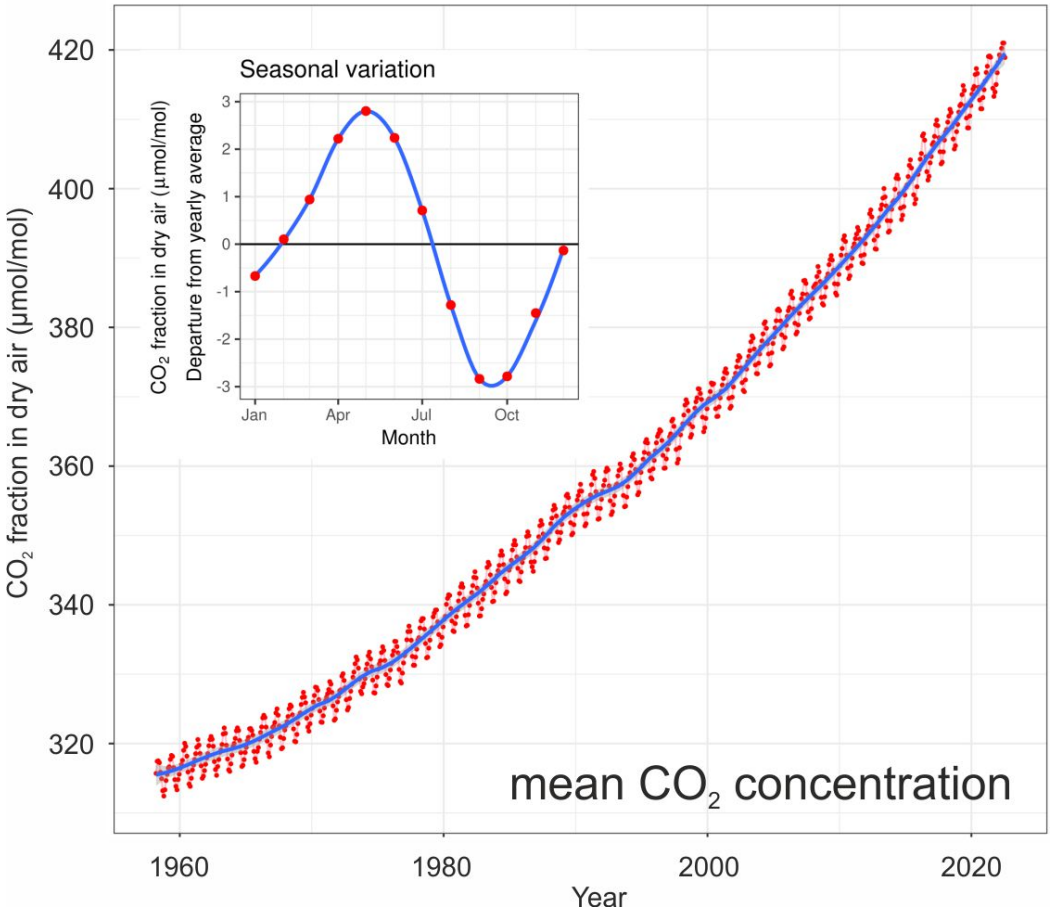
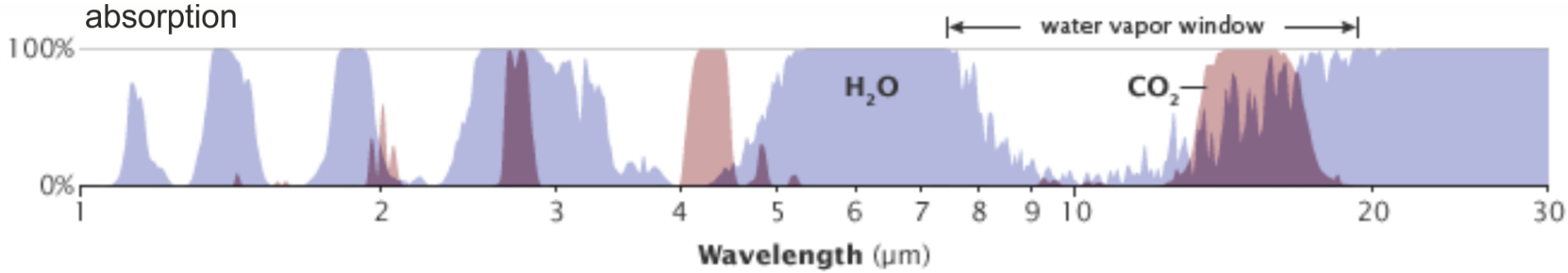
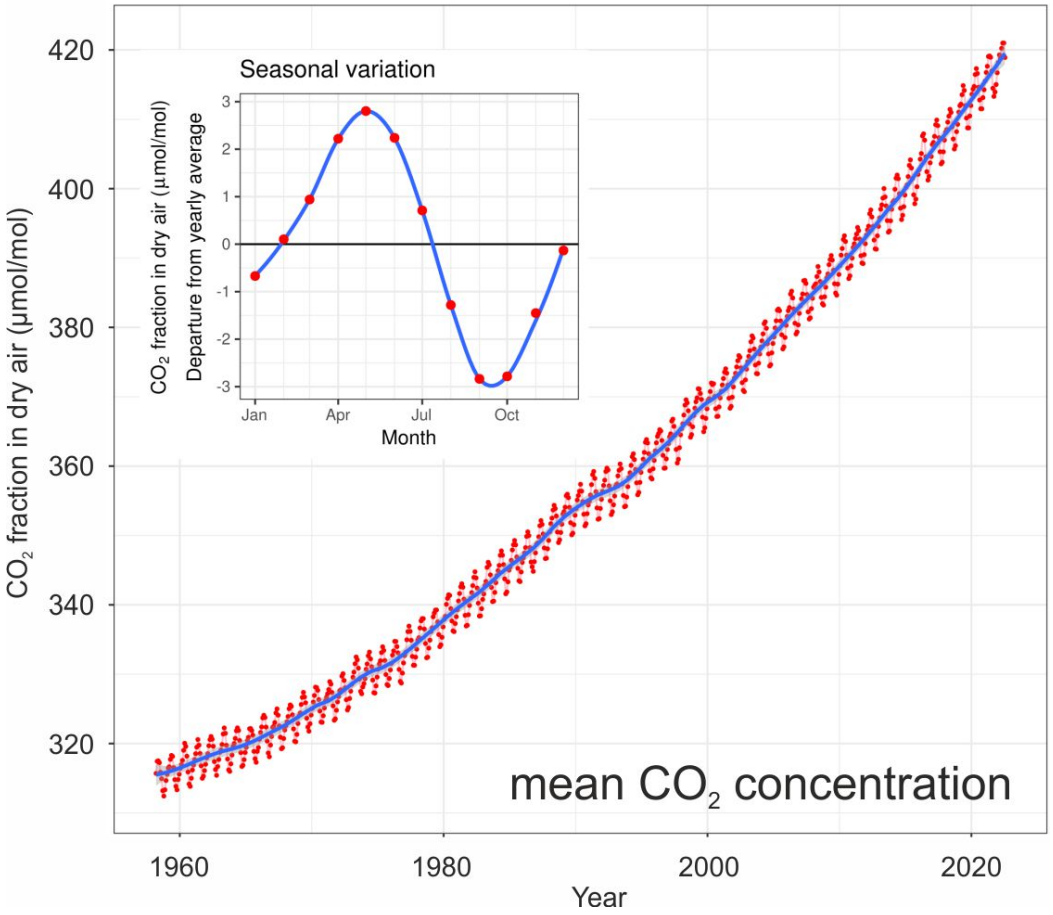


Image credits: NASA (public domain) and Delorme (CC-BY-SA)

Greenhouse gases





Non-polar molecules
do not absorb IR radiation

Image credits: NASA (public domain) and Delorme (CC-BY-SA)

Experimental technique

infrared spectroscopy

Experimental setup

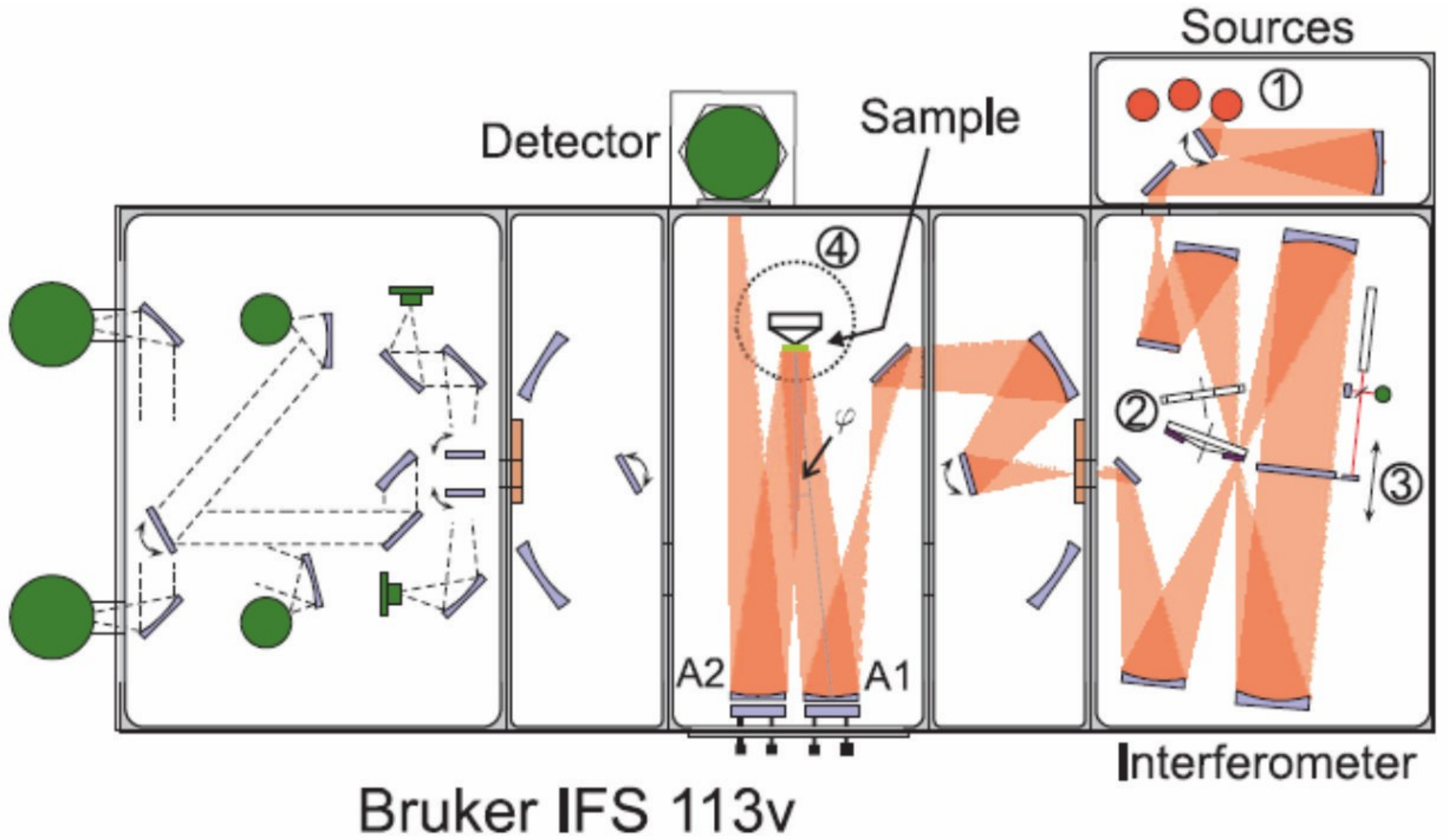
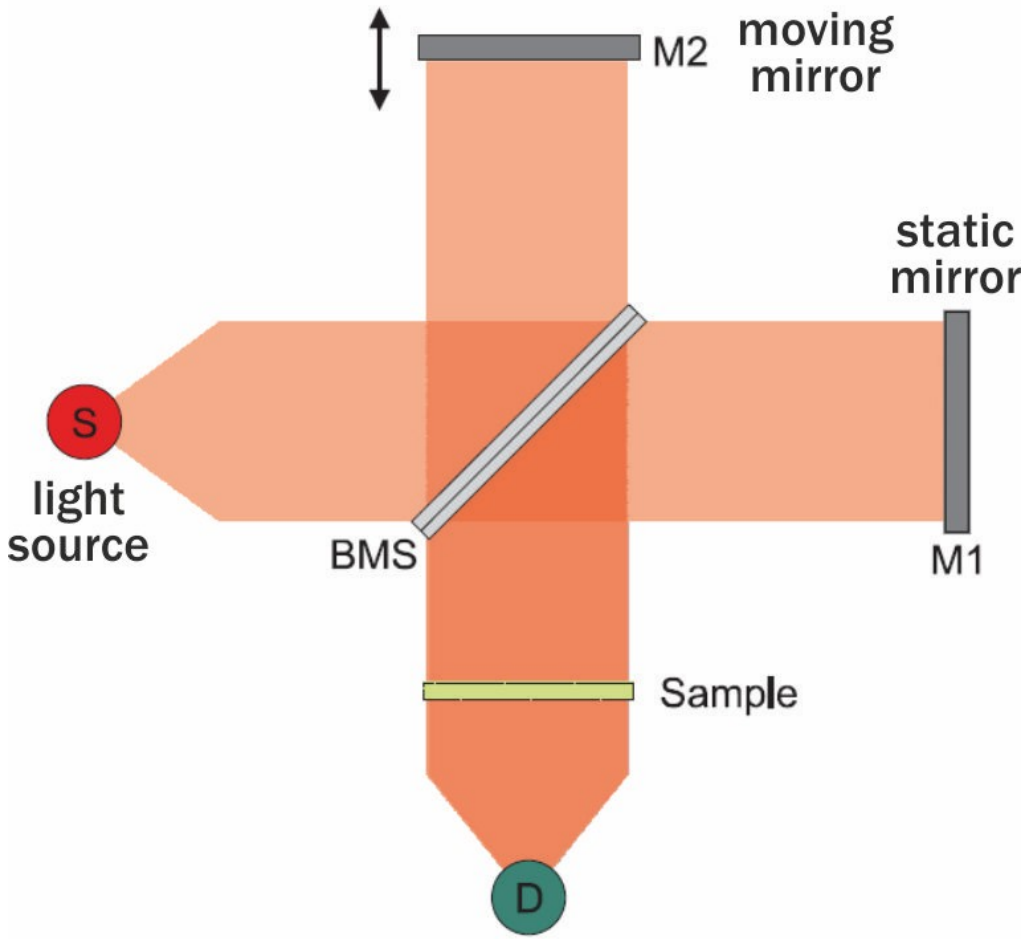


Image credit: David Neubauer, PhD thesis

Interferometer: operation principle



Moving mirror modulates the interference signal

It can be “decoded” into a frequency dependence

Image credit: David Neubauer, PhD thesis

Interferometer: operation principle

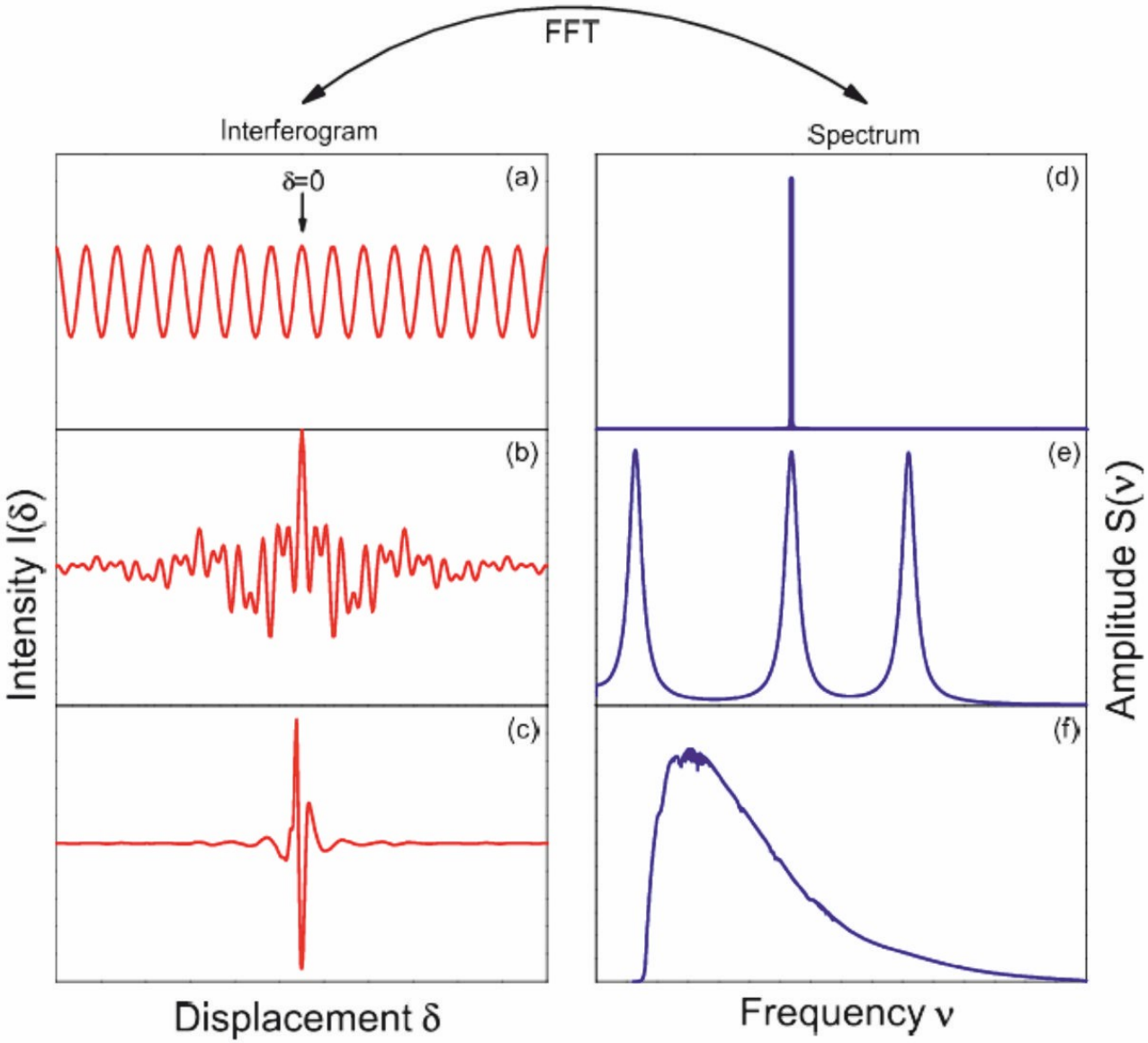
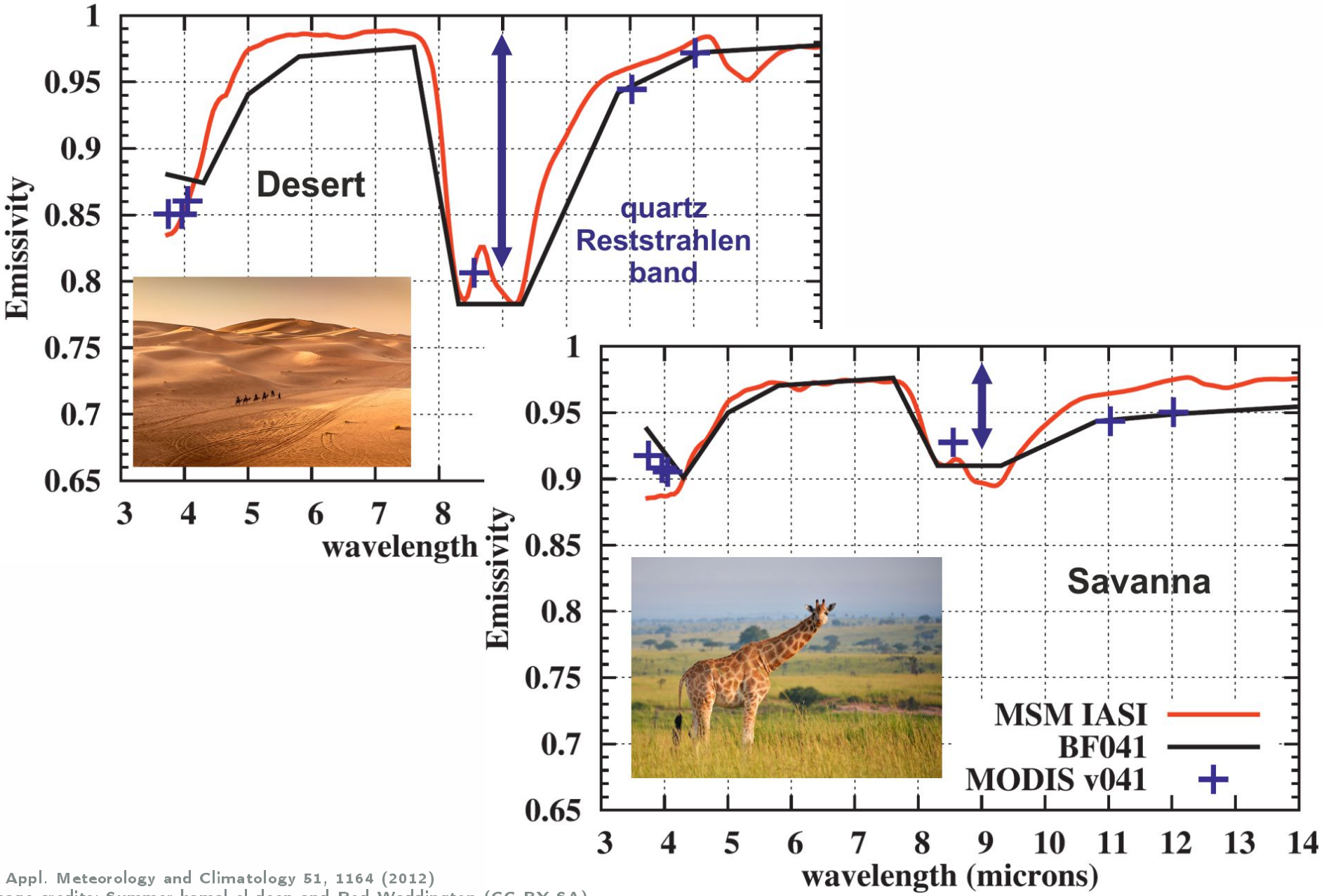


Image credit: David Neubauer, PhD thesis

IR spectroscopy in geoscience



J. Appl. Meteorology and Climatology 51, 1164 (2012)
Image credits: Summer kamal el deen and Rod Waddington (CC-BY-SA)