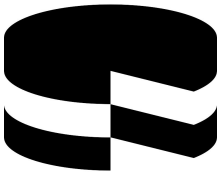
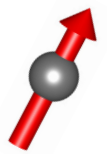
Optical properties of metals

optical spectroscopy



coinage metals

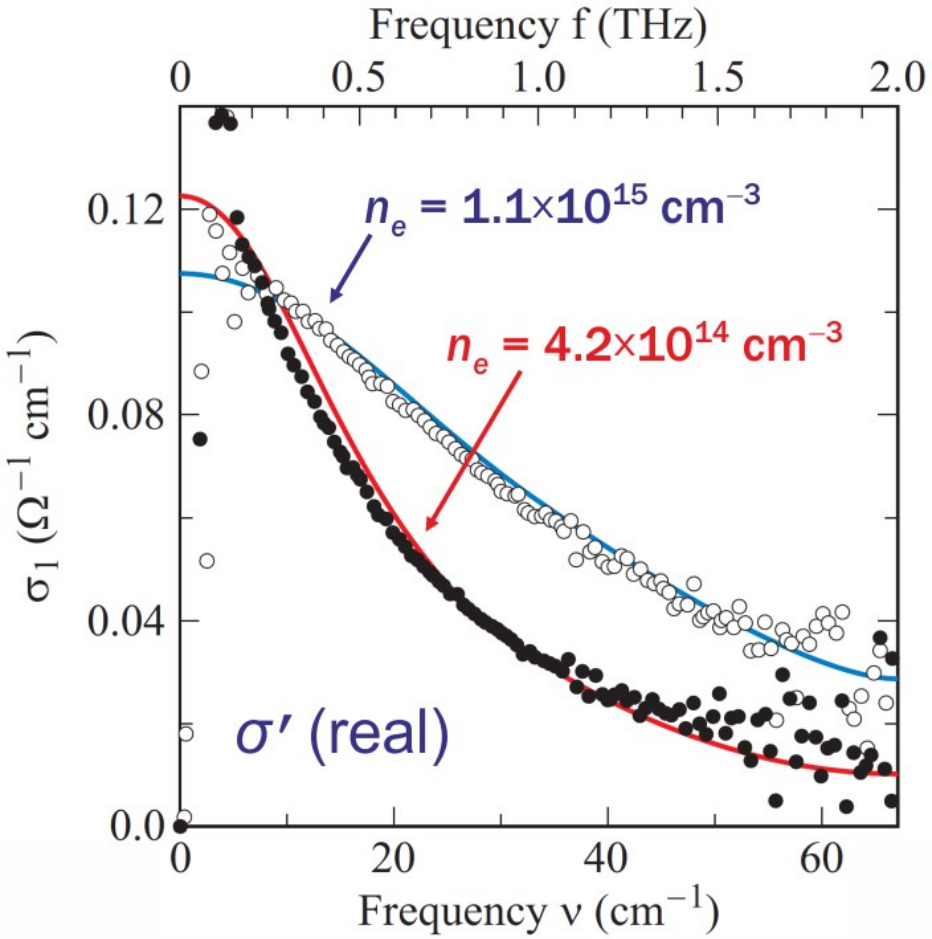
Kramers and Kronig

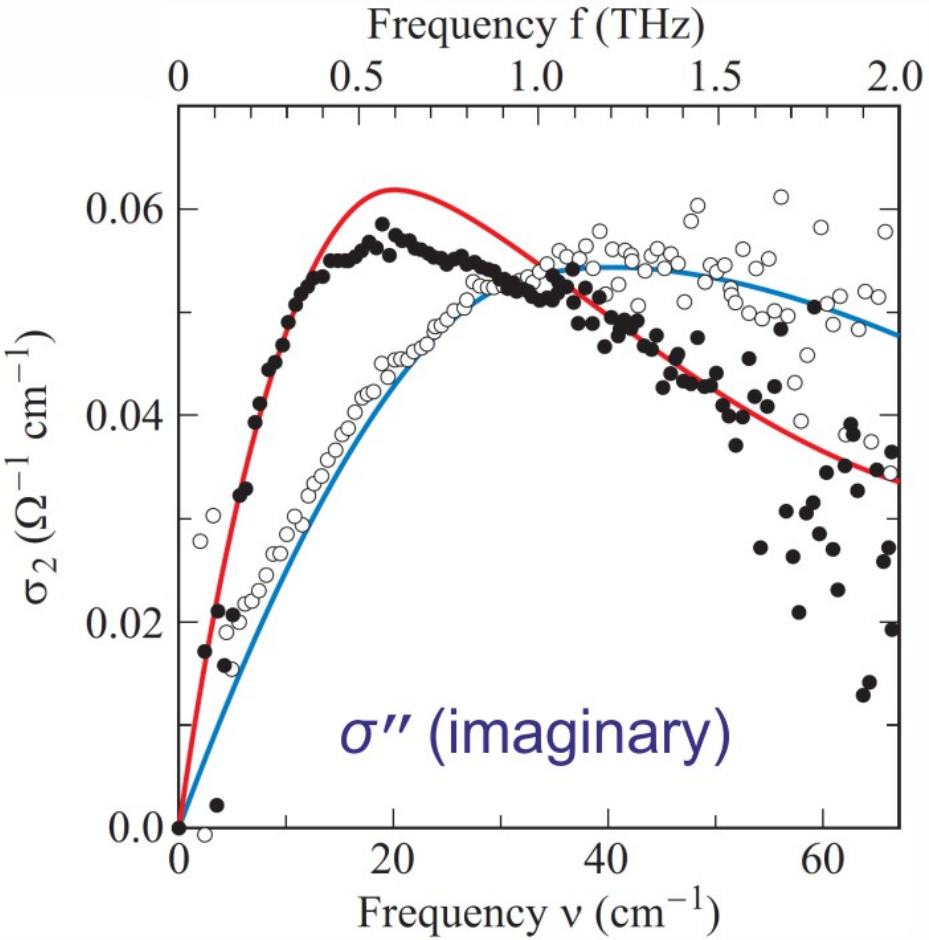


by Alexander Tsirlin, Leipzig University

Lecture 20: January 3, 2024

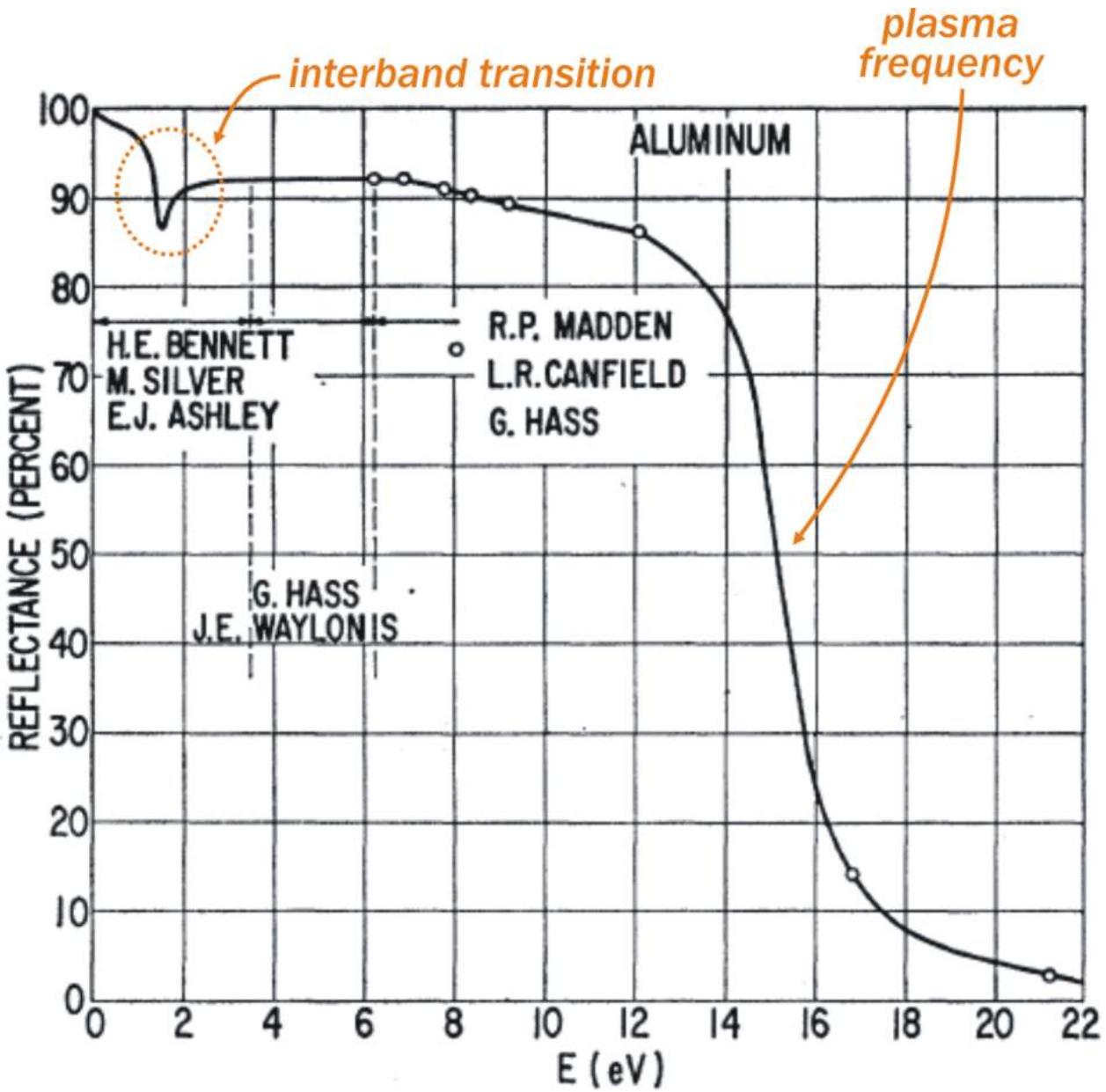
Drude optical conductivity





Drude behavior is observed in the optical conductivity even at low electron concentrations

Ann. Phys. (Leipzig) 15, 535 (2006)

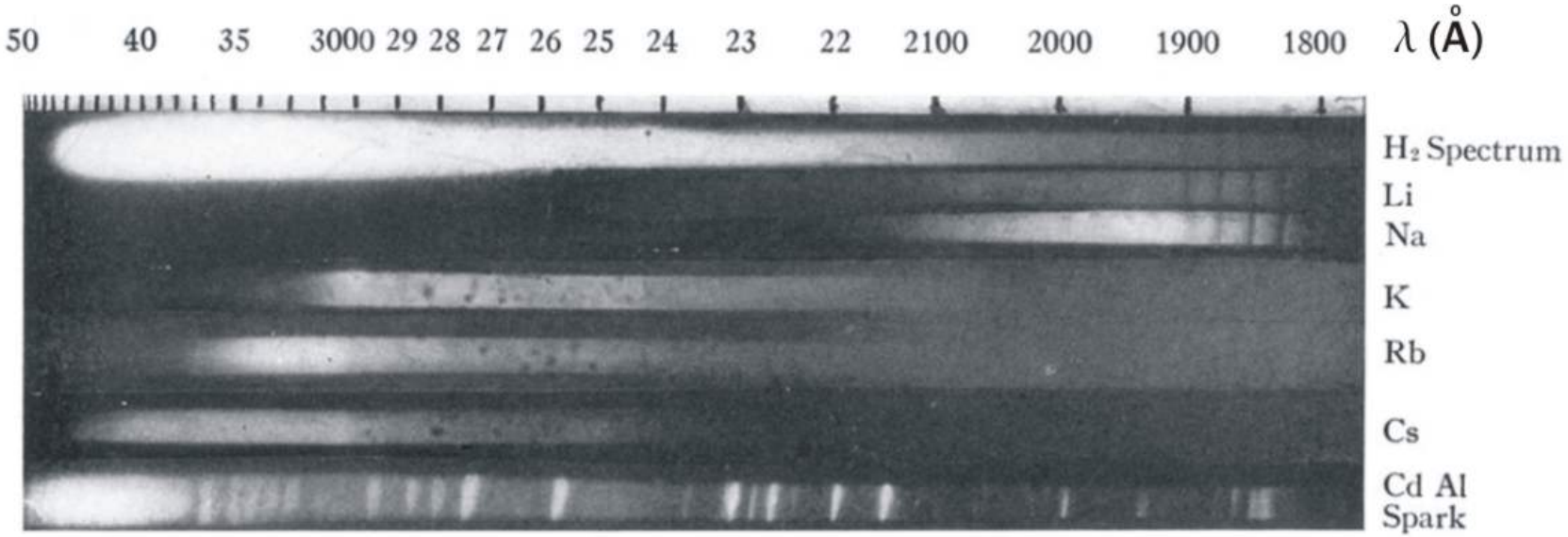


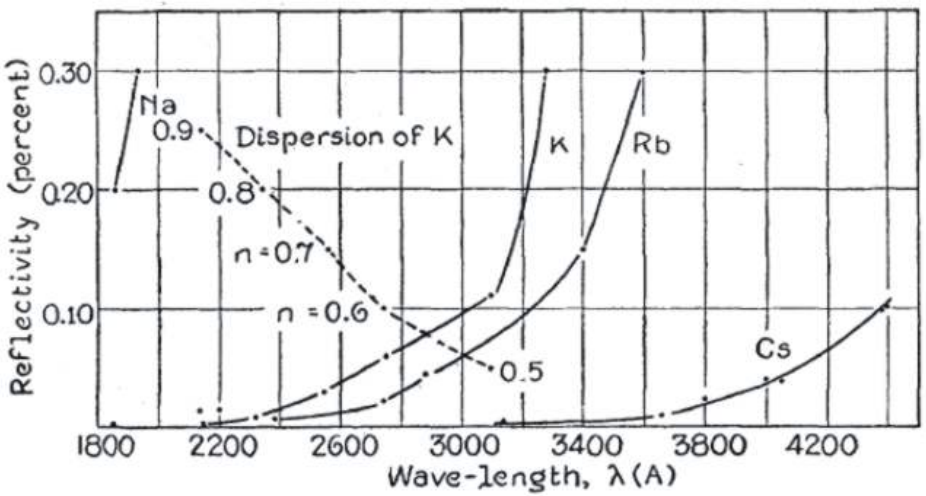
Al becomes transparent above $\sim 15\,\mathrm{eV}$

in agreement with the Drude model

Phys. Rev. 132, 1918 (1963)

Plasma edge of alkaline metals





Alkaline metals become transparent in the UV range

λ_c: Cs > Rb > K > Na

Phys. Rev. 44, 353 (1933)

Heatable glass

Tinted glass

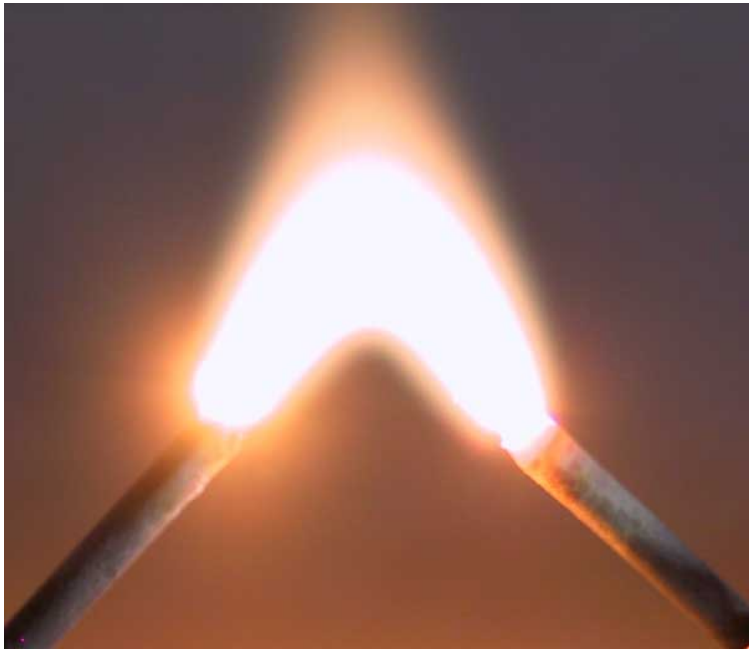
Heatable glass

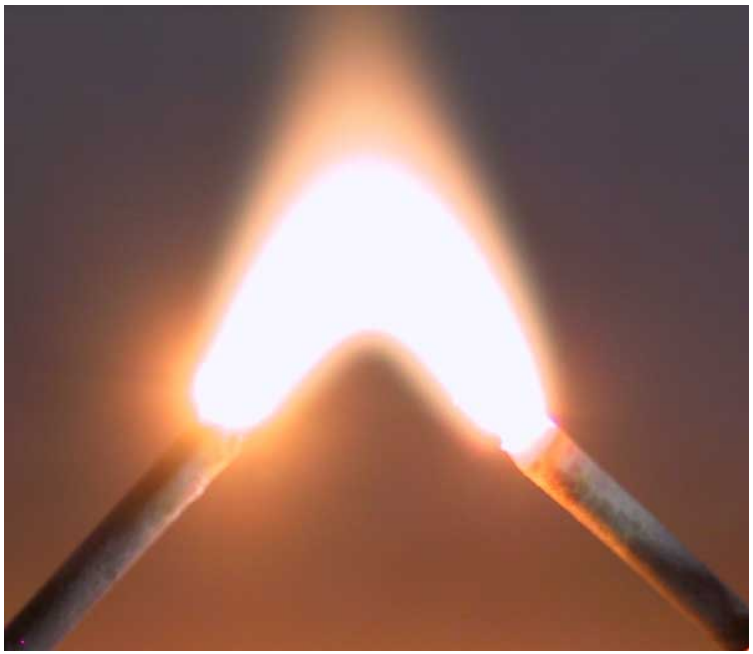
- Keeps heat inside, reflects heat from the outside
- Ultra-thin metal layers or conducting oxides with low n_e values:
  ITO (In-doped SnO_2), FTO (F-doped SnO_2), etc.

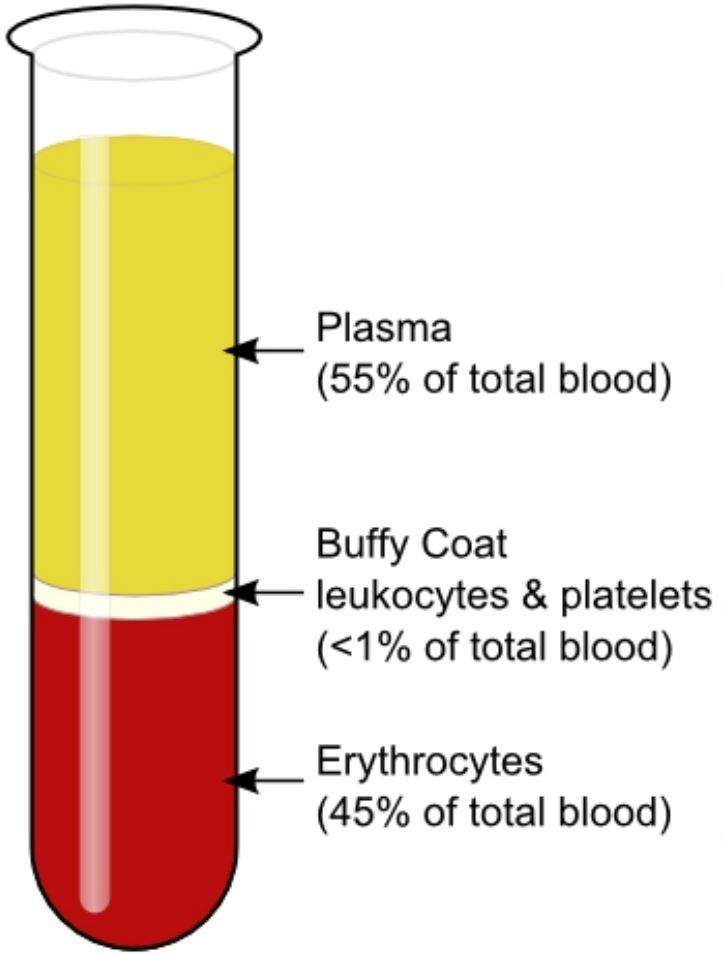
Image credits: Chrysler, AliExpress

Why plasma?

Why plasma?







Experimental technique

optical spectroscopy

Experimental setup

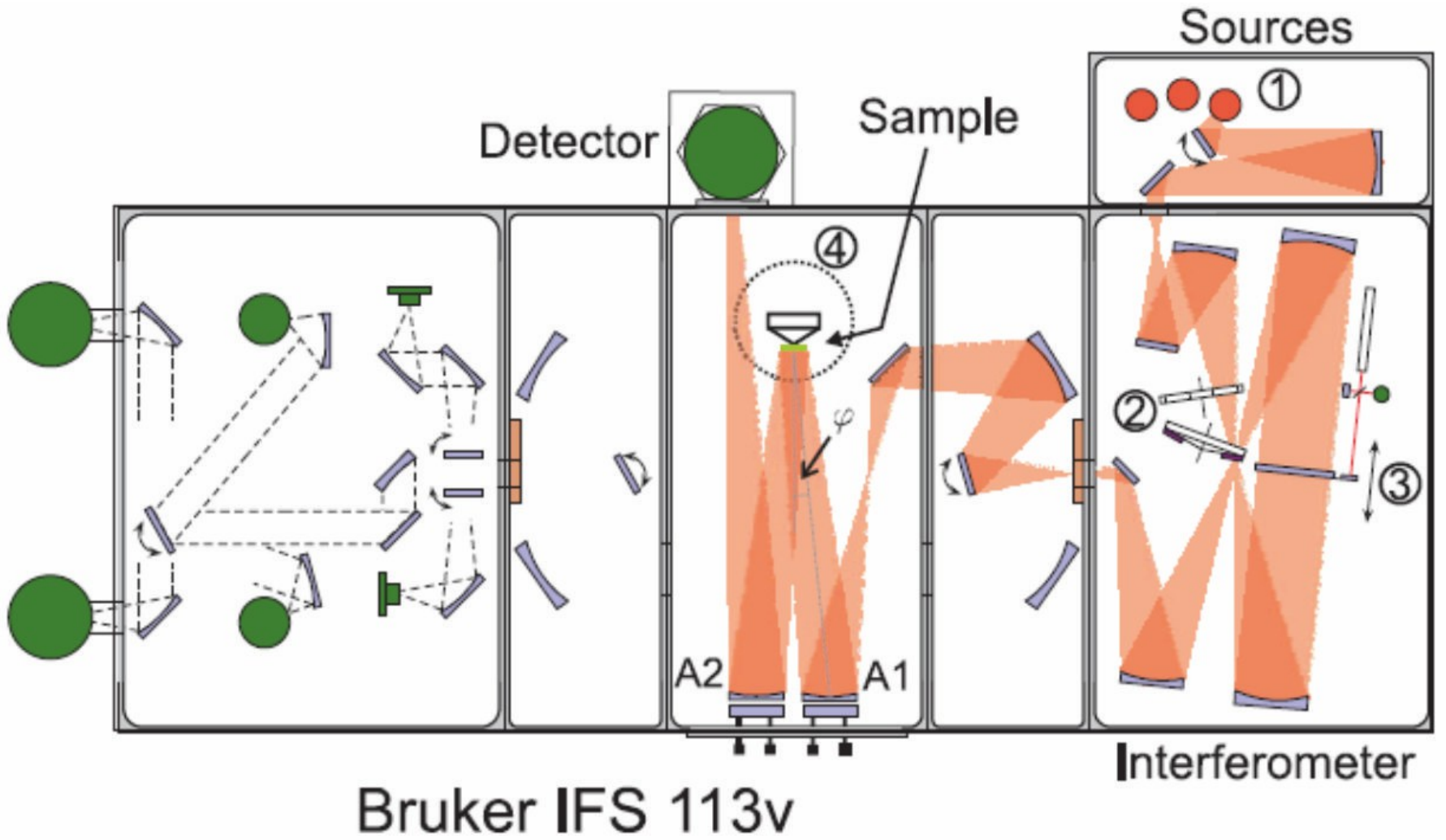


Image credit: David Neubauer, PhD thesis

Interferometer: operation principle

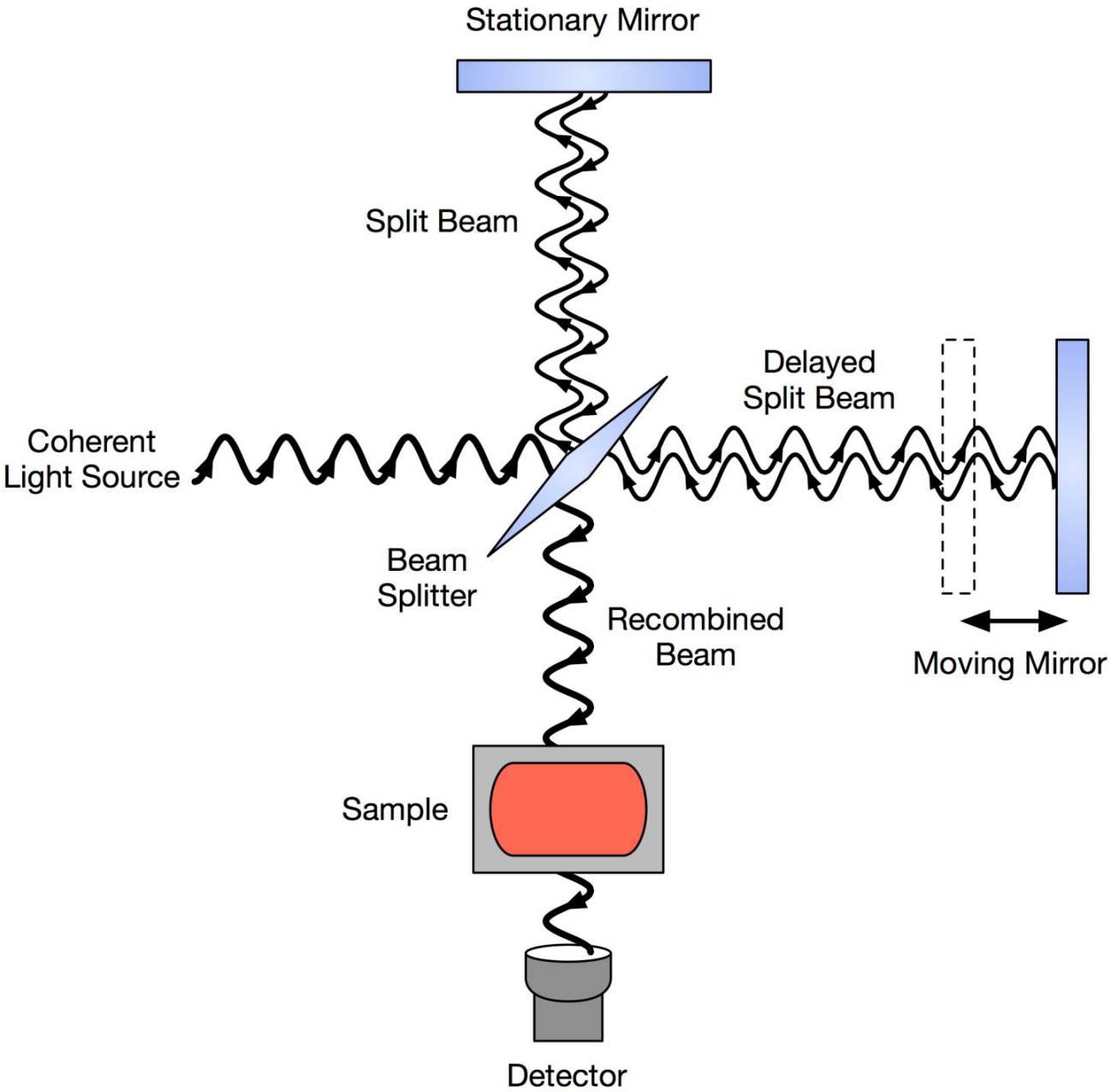


Image credit: Sanchonx (public domain)

Interferometer: operation principle

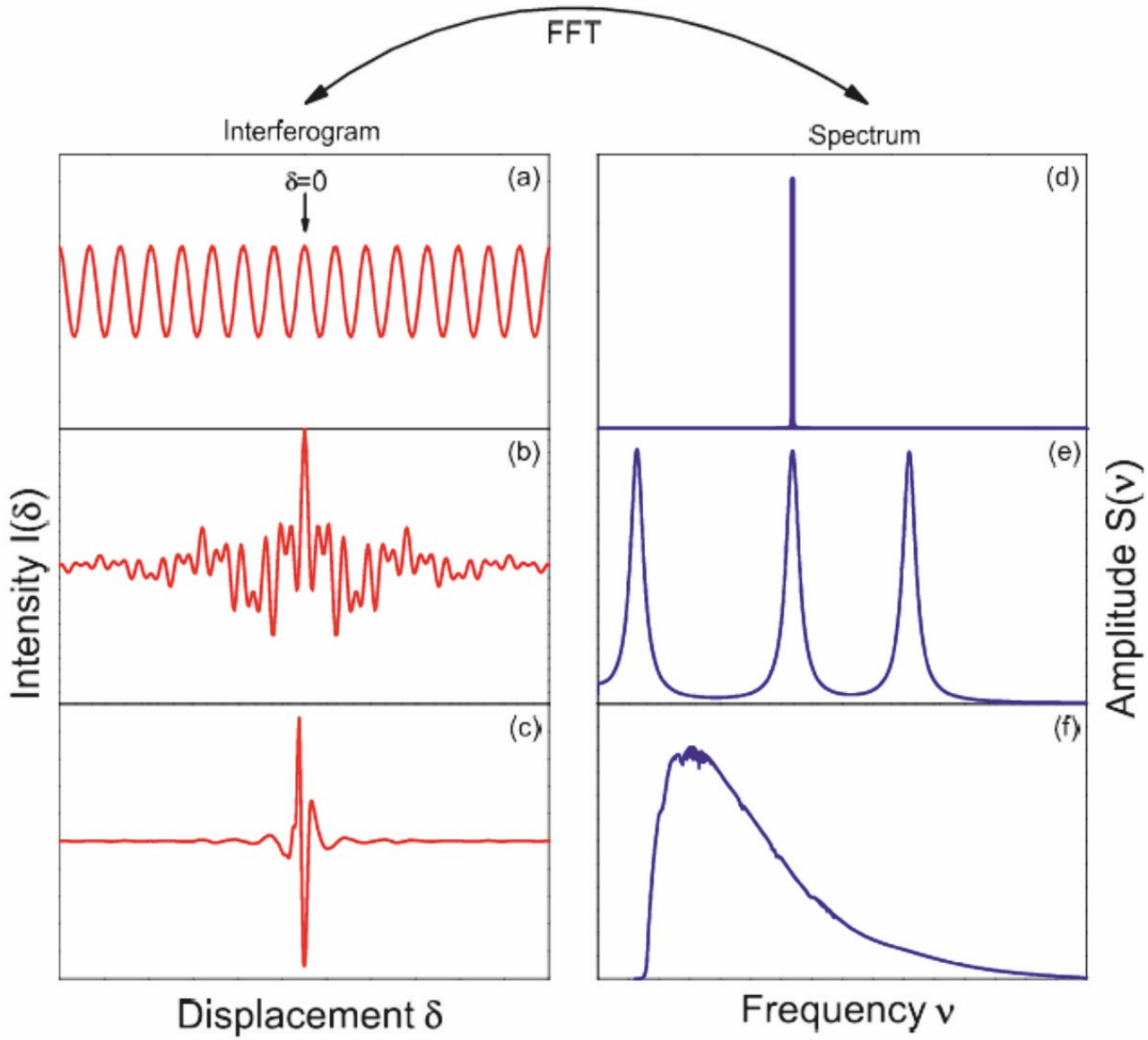
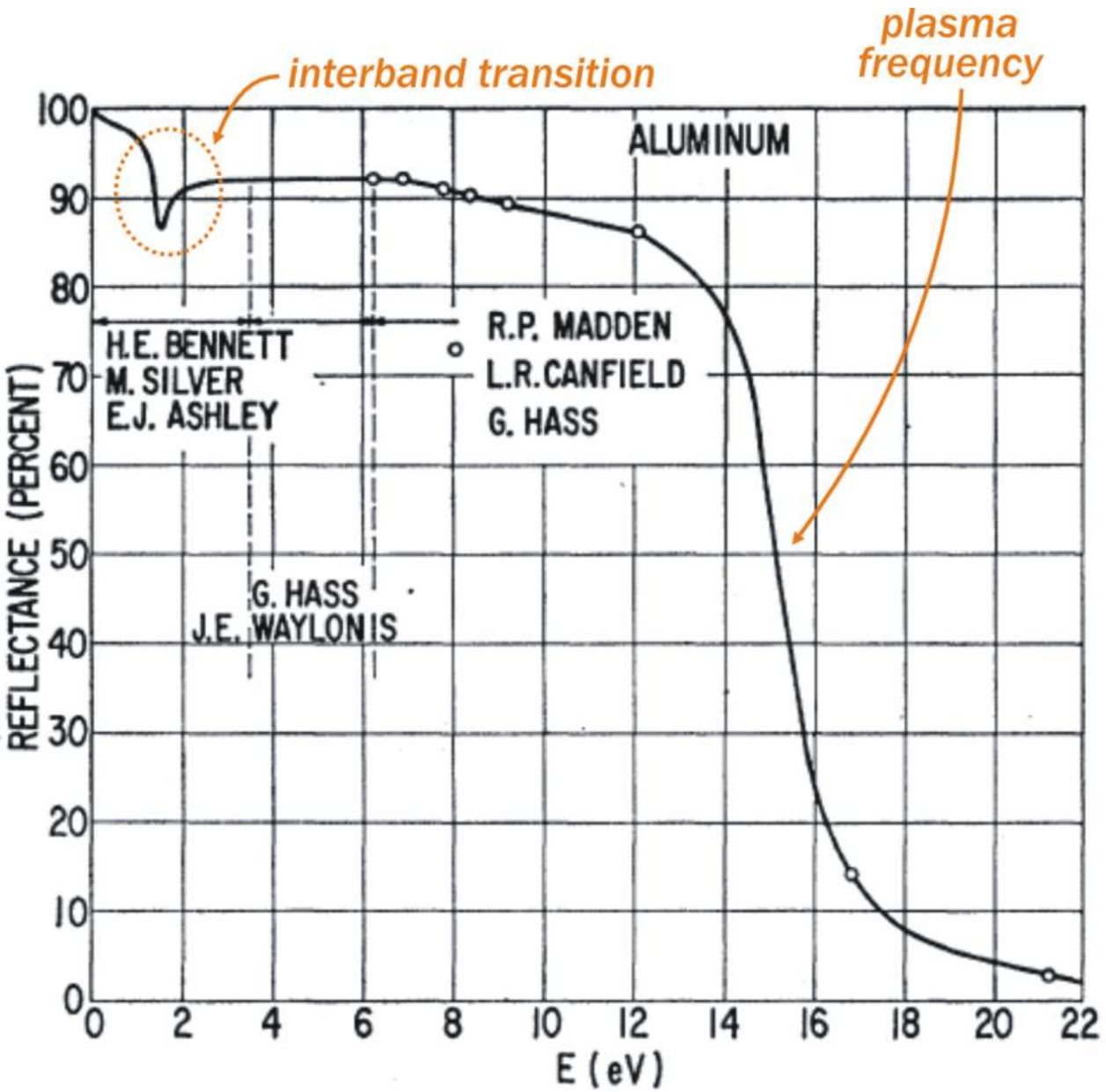


Image credit: David Neubauer, PhD thesis



Reflectivity is easiest to measure experimentally

broad frequency range required

Phys. Rev. 132, 1918 (1963)

Region	Measurement range	Light source	Beamsplitter	Detector
Far infrared_1	$20 \sim 120$ cm^{-1}	Mercury Lamp	Mylar 50 μm	1.7 K Bolometer
Far infrared_2	$50 \sim 600$ cm^{-1}	Mercury Lamp	Mylar 6 μm	4.2 K Bolometer
Middle infrared	$550 \sim 5000$ cm^{-1}	Globar Lamp	Ge/KBr	DTGS
Near infrared	$3500 \sim 10000$ cm^{-1}	Tungsten Lamp	Si/CaF_2	InGaAs Diode
Visible	$9000 \sim 20000$ cm^{-1}	Tungsten Lamp	UV/CaF_2	Silicon Diode

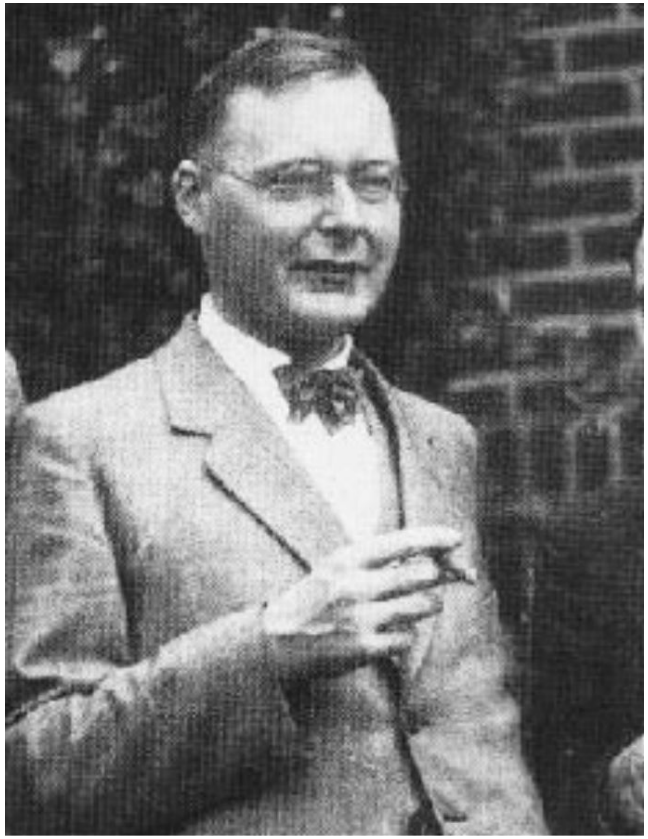
Region	Inner windows	Outer windows	Polarizer
Far infrared_1	polypropylene	polypropylene	polyethylene wire grid
Far infrared_2	polypropylene	polypropylene	polyethylene wire grid
Middle infrared	Zn-Se	KBr	KRS-250 wire grid
Near infrared	quartz	quartz	Glan-Taylor prism
Visible	quartz	quartz	Glan-Taylor prism

Source: Ece Uykur, PhD thesis

Person

Kramers and Kronig

Kramers and Kronig



Hendrik Kramers
1894–1952

Ralph Kronig
1904–1995

Paul Ehrenfest: *you don't yet have a reputation, so you have nothing to lose*

Example

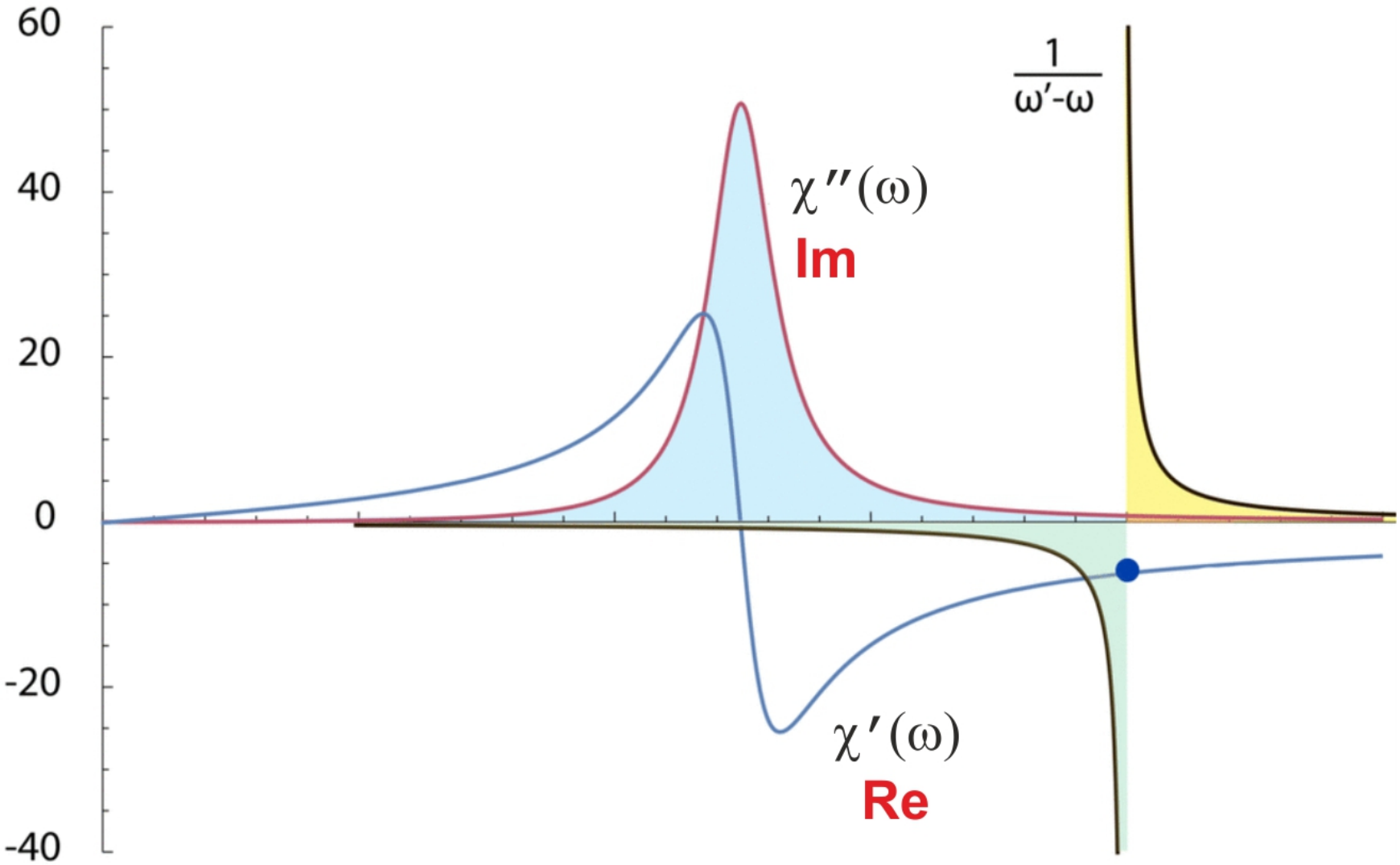
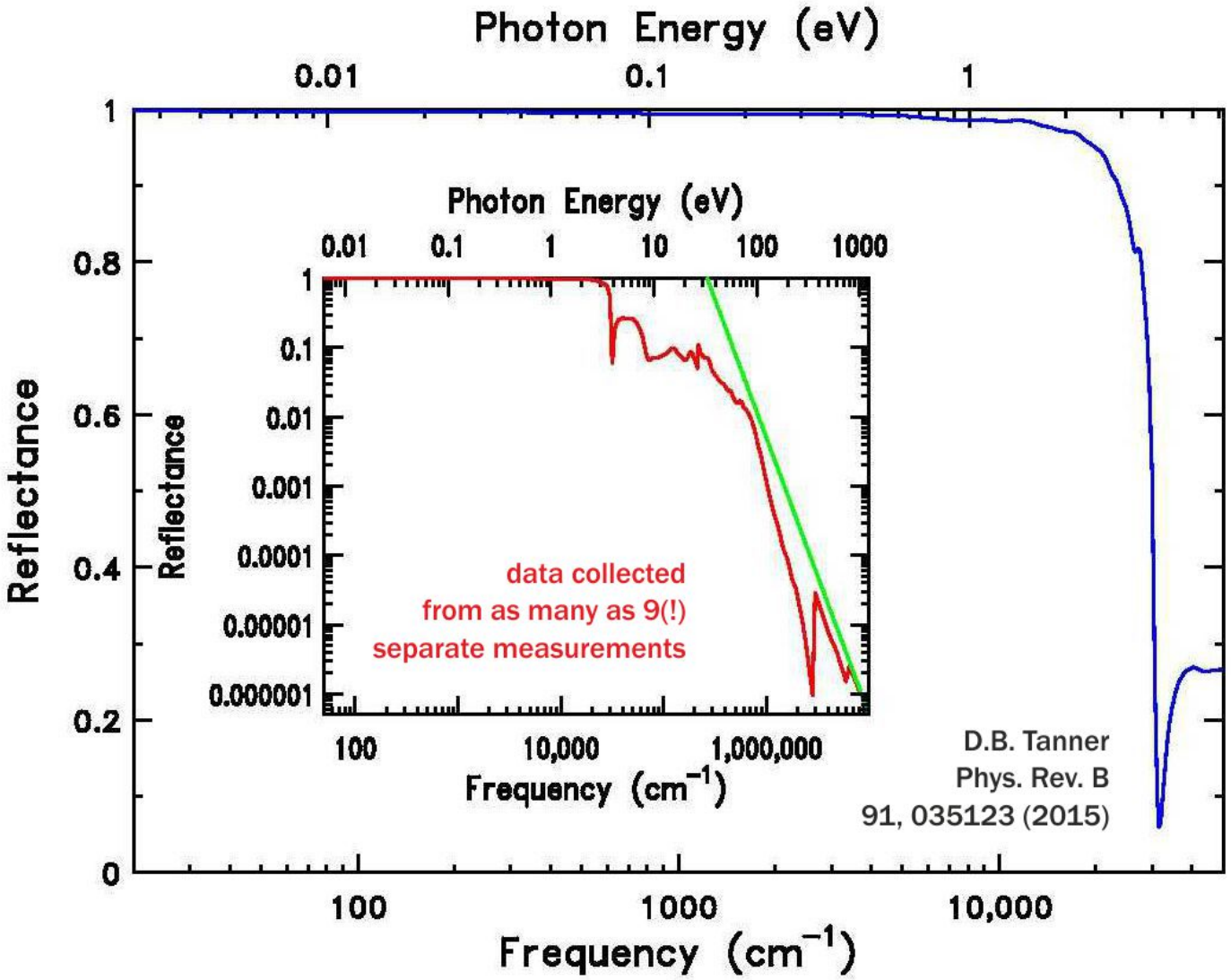


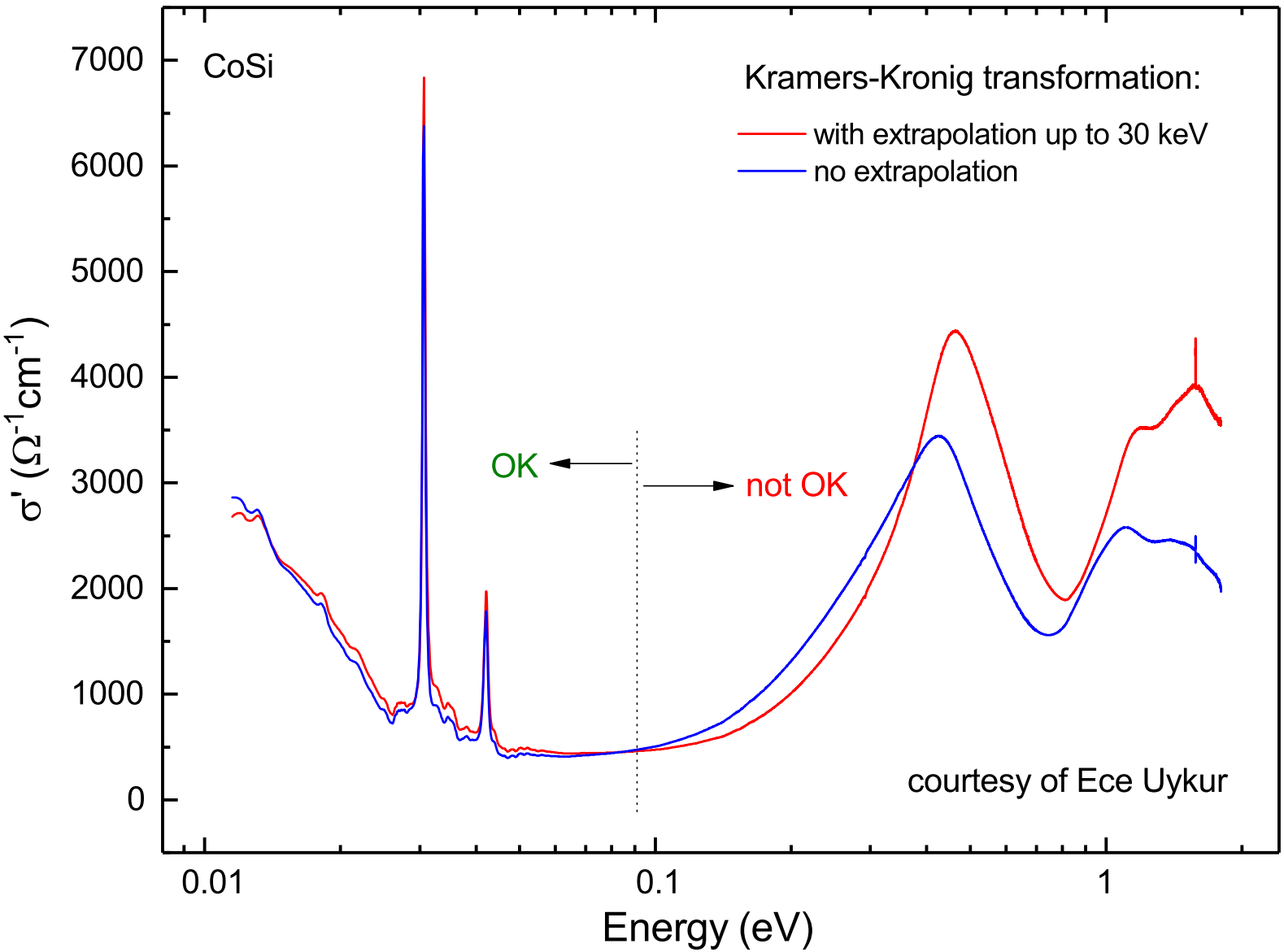
Image credit: Zefr (CC-zero)

Problem of extrapolation

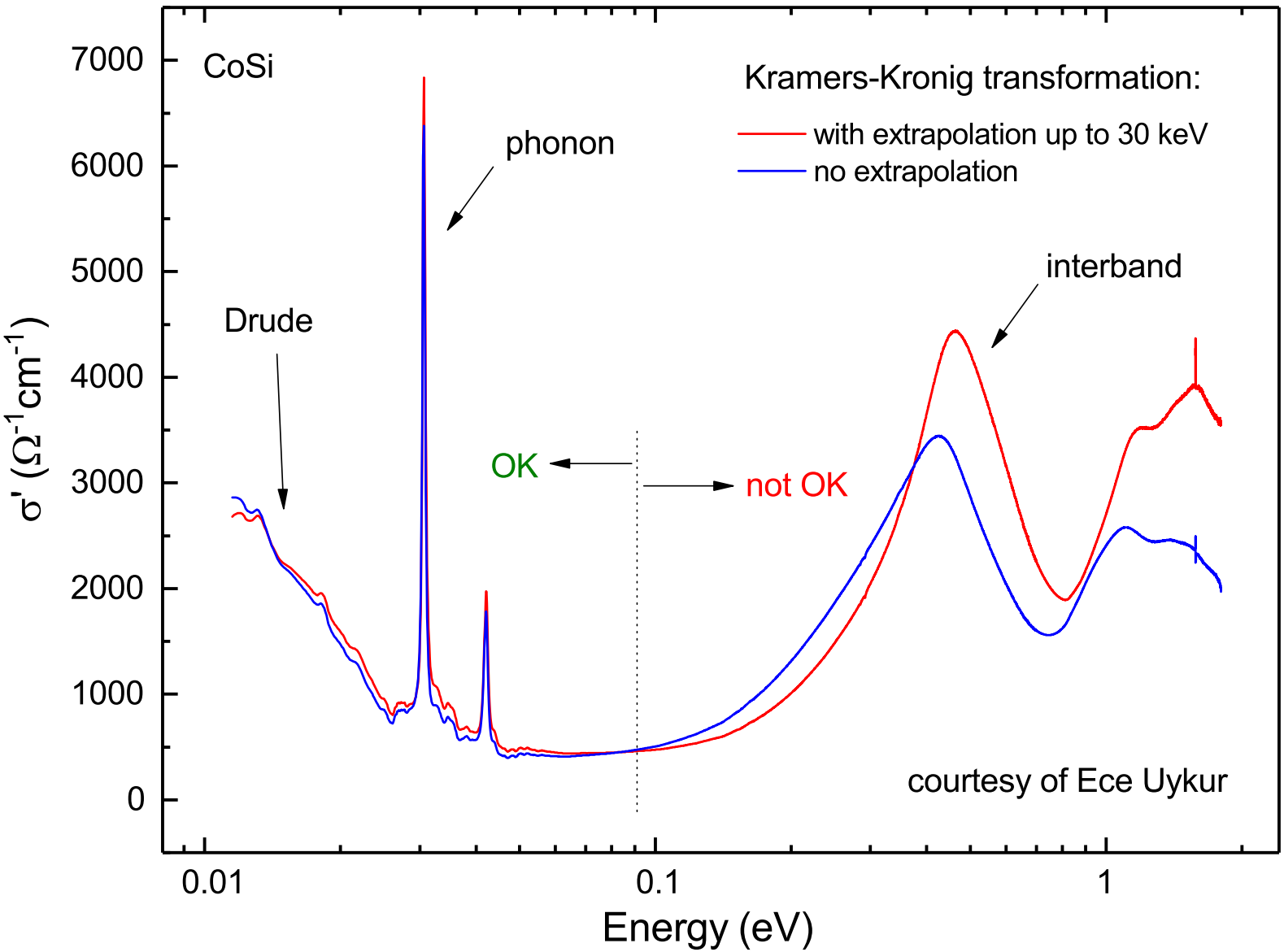


Non-trivial spectral features occur even at very high energies

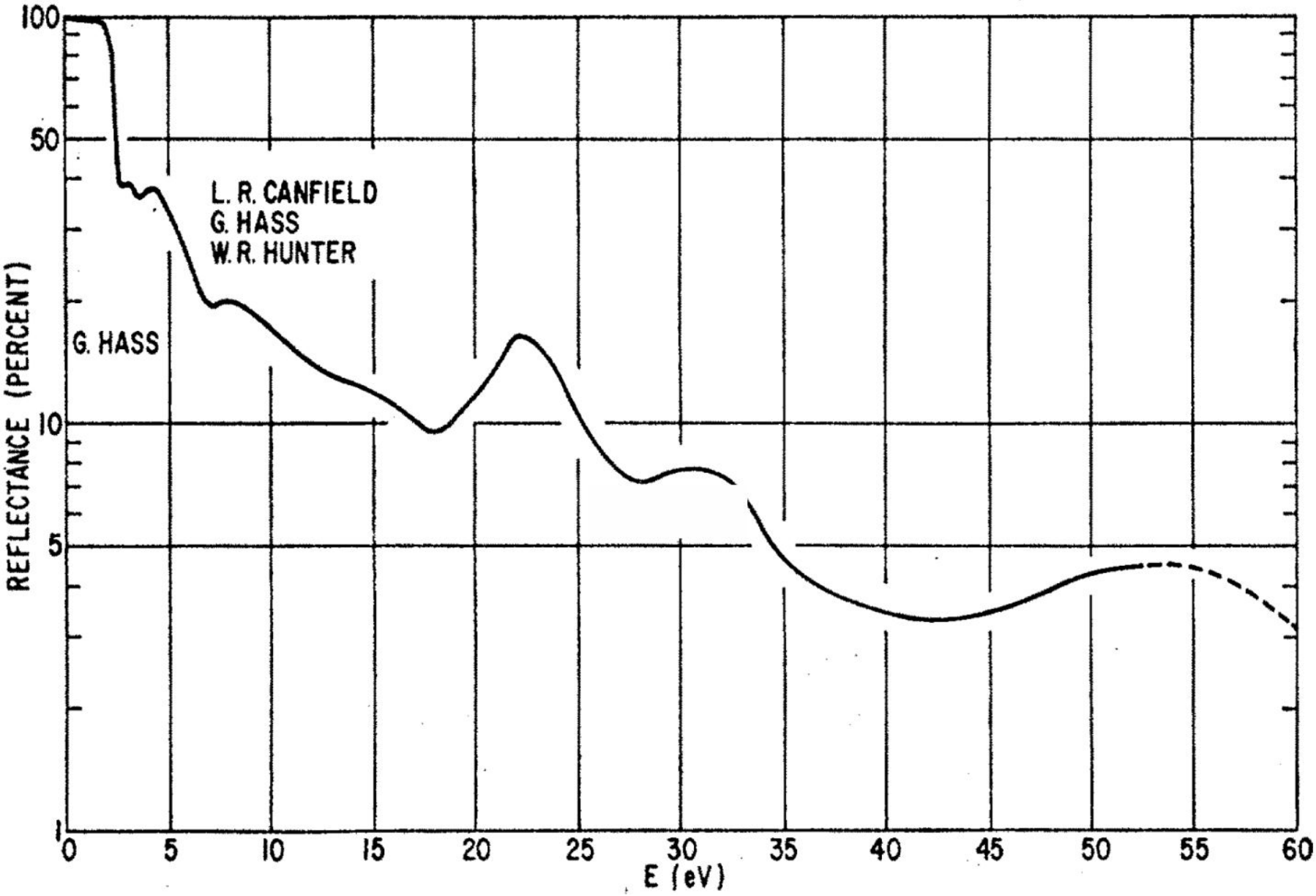
Problem of extrapolation



Problem of extrapolation

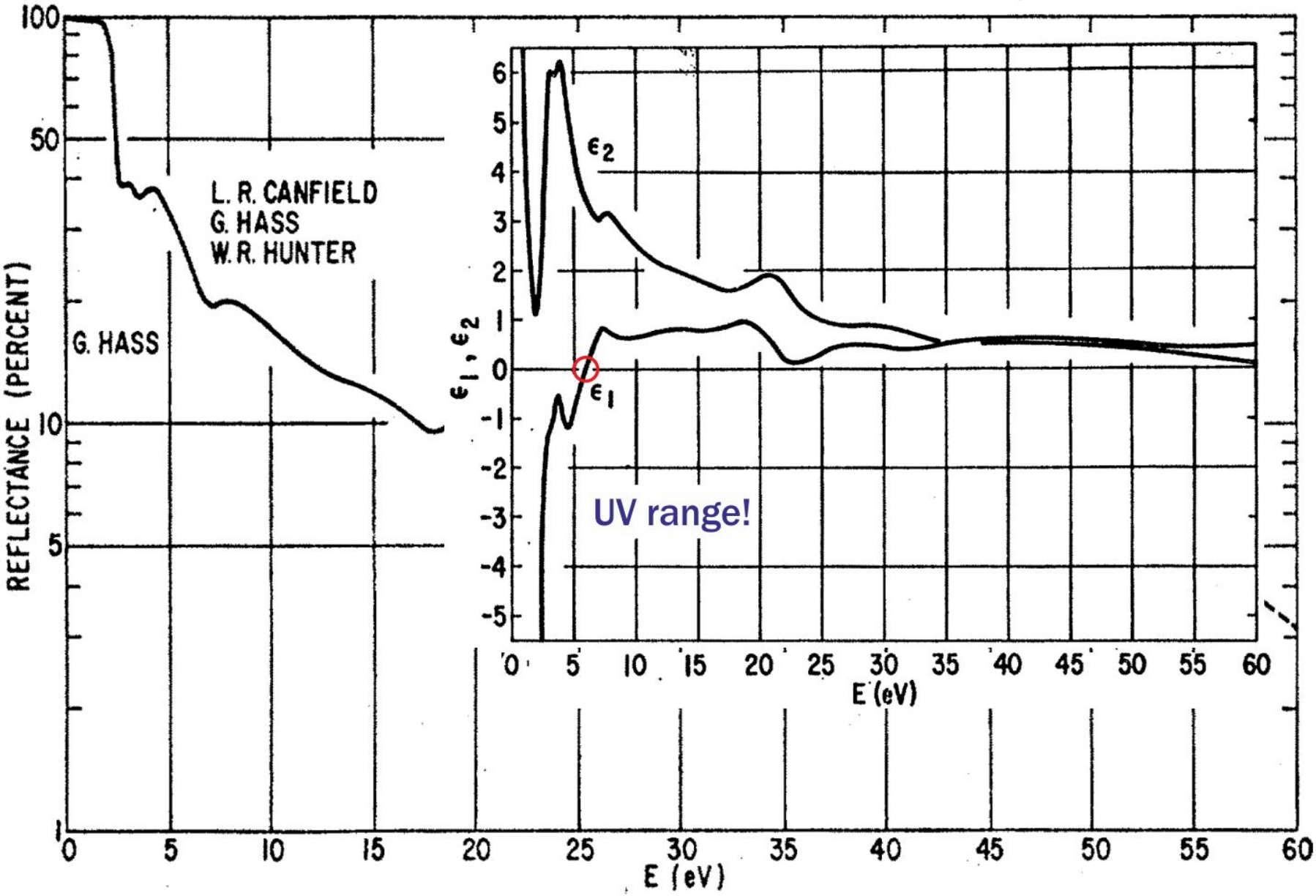


Reflectivity of gold

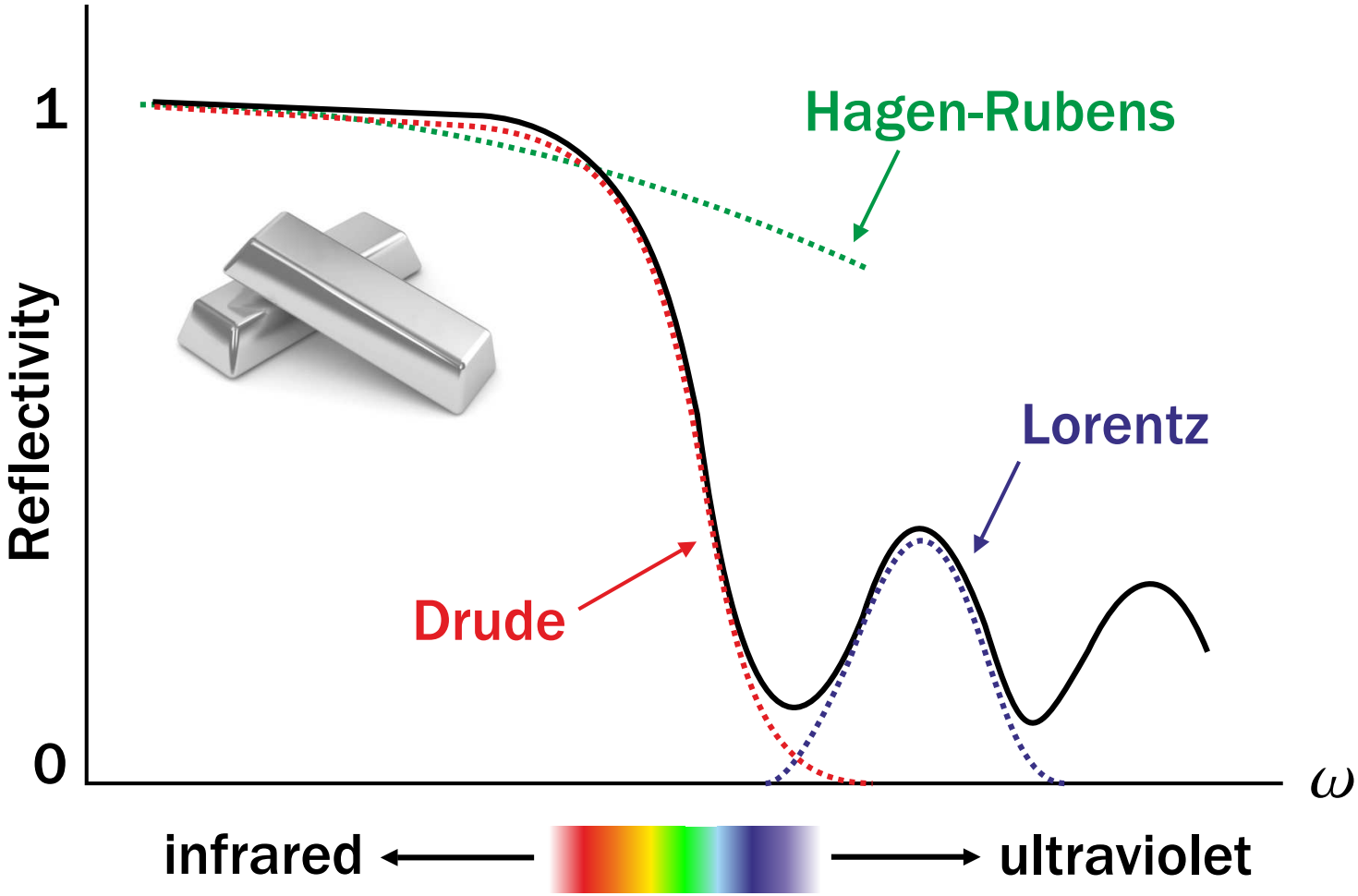


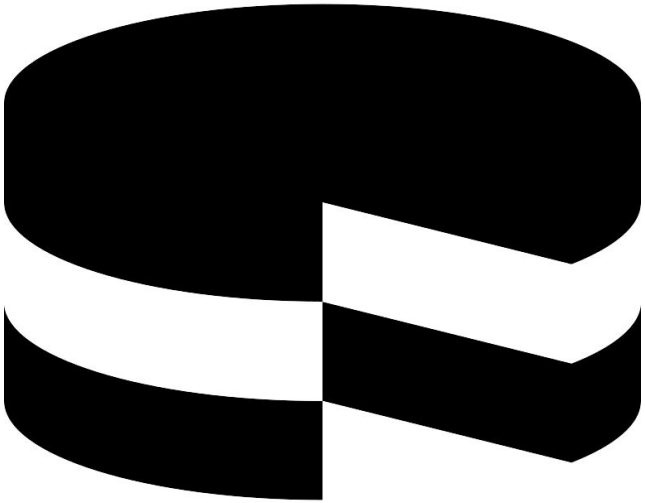
Phys. Rev. 138, A494 (1965)

Reflectivity of gold



Phys. Rev. 138, A494 (1965)


1
0
Reflectivity
Hagen-Rubens
Lorentz
Drude
ω
infrared
ultraviolet



Material

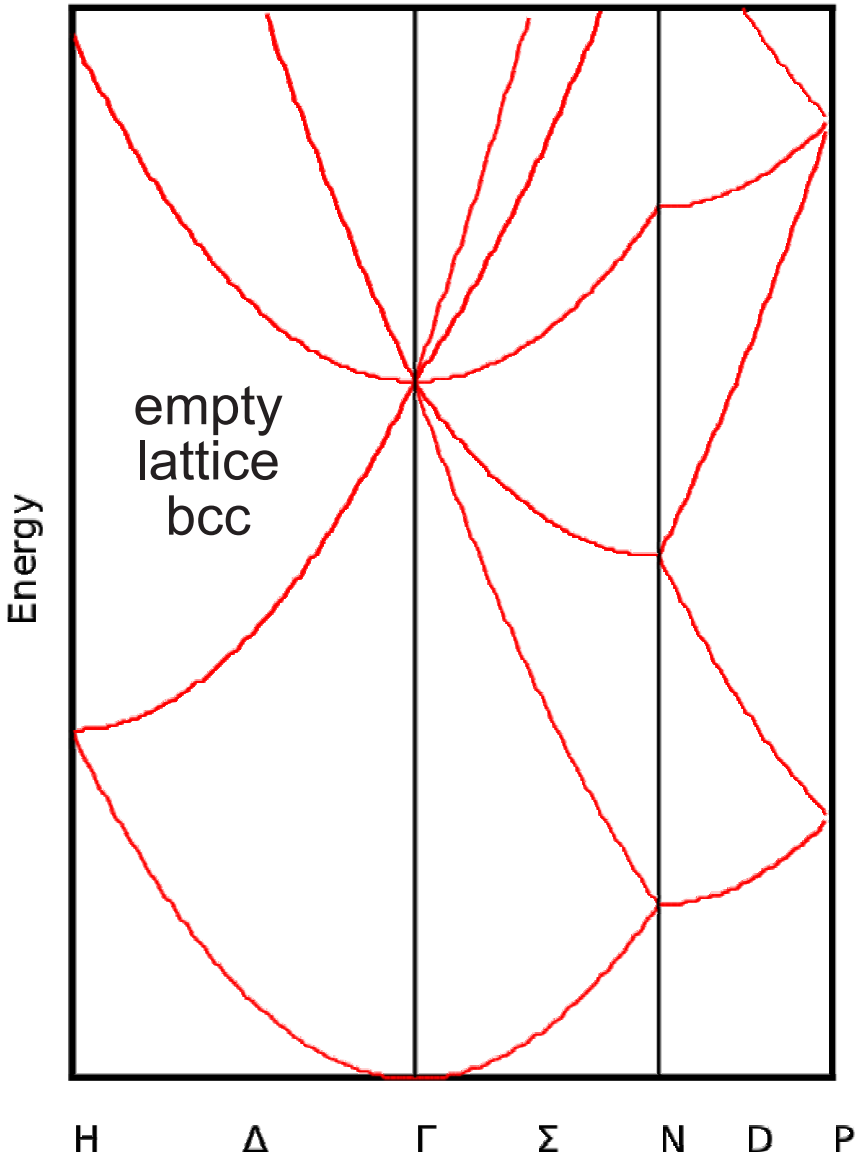
coinage metals

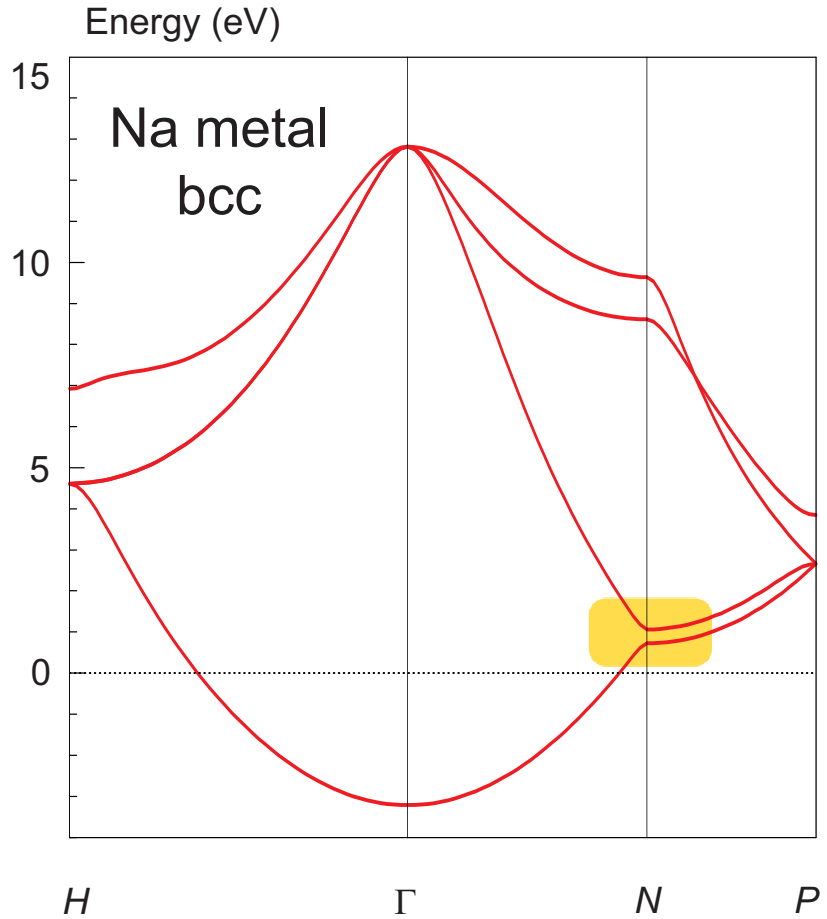
Coinage metals

1																	18
1 H 1.0079	2											13	14	15	16	17	2 He 4.0026
3 Li 6.941	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305	3	4	5	6	7	8	9	10	11	12	13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.065	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.867	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.38	31 Ga 69.723	32 Ge 72.64	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.798
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.96	43 Tc -	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57-71	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po -	85 At -	86 Rn -
87 Fr -	88 Ra -	89-103	104 Rf -	105 Db -	106 Sg -	107 Bh -	108 Hs -	109 Mt -	110 Ds -	111 Rg -							

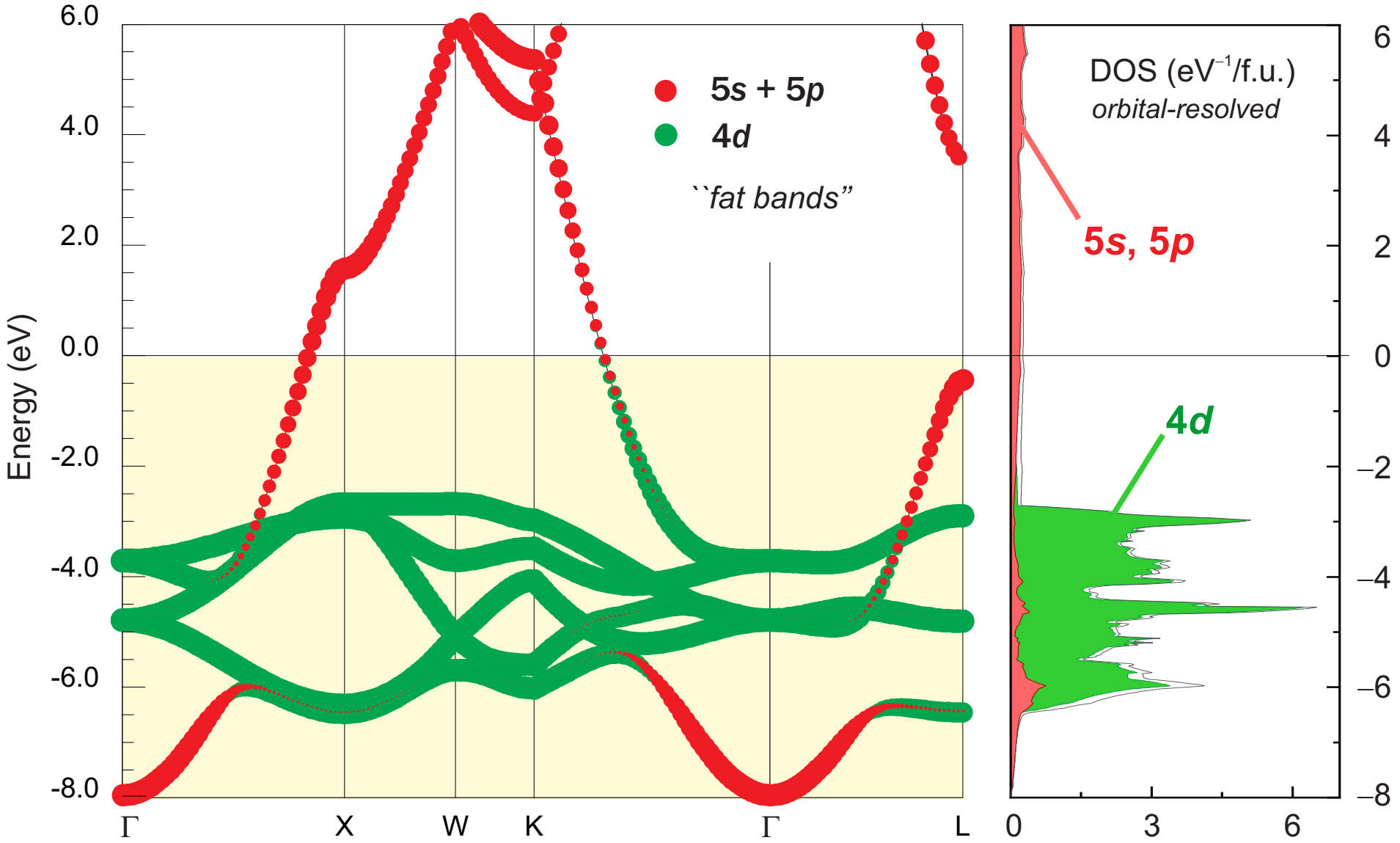
57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm -	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97
89 Ac -	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np -	94 Pu -	95 Am -	96 Cm -	97 Bk -	98 Cf -	99 Es -	100 Fm -	101 Md -	102 No -	103 Lr -

Monovalent metal (empty-lattice approximation)

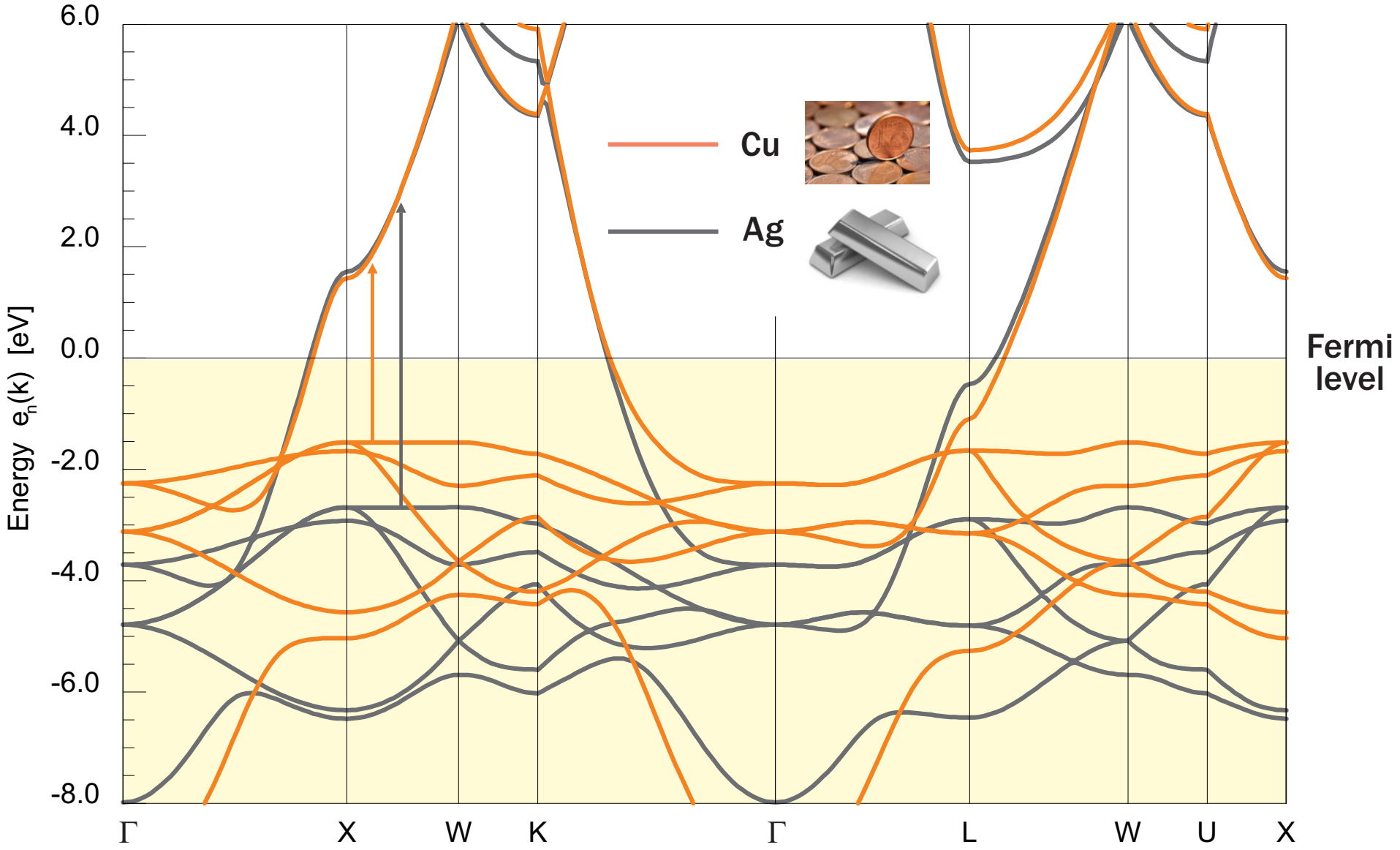




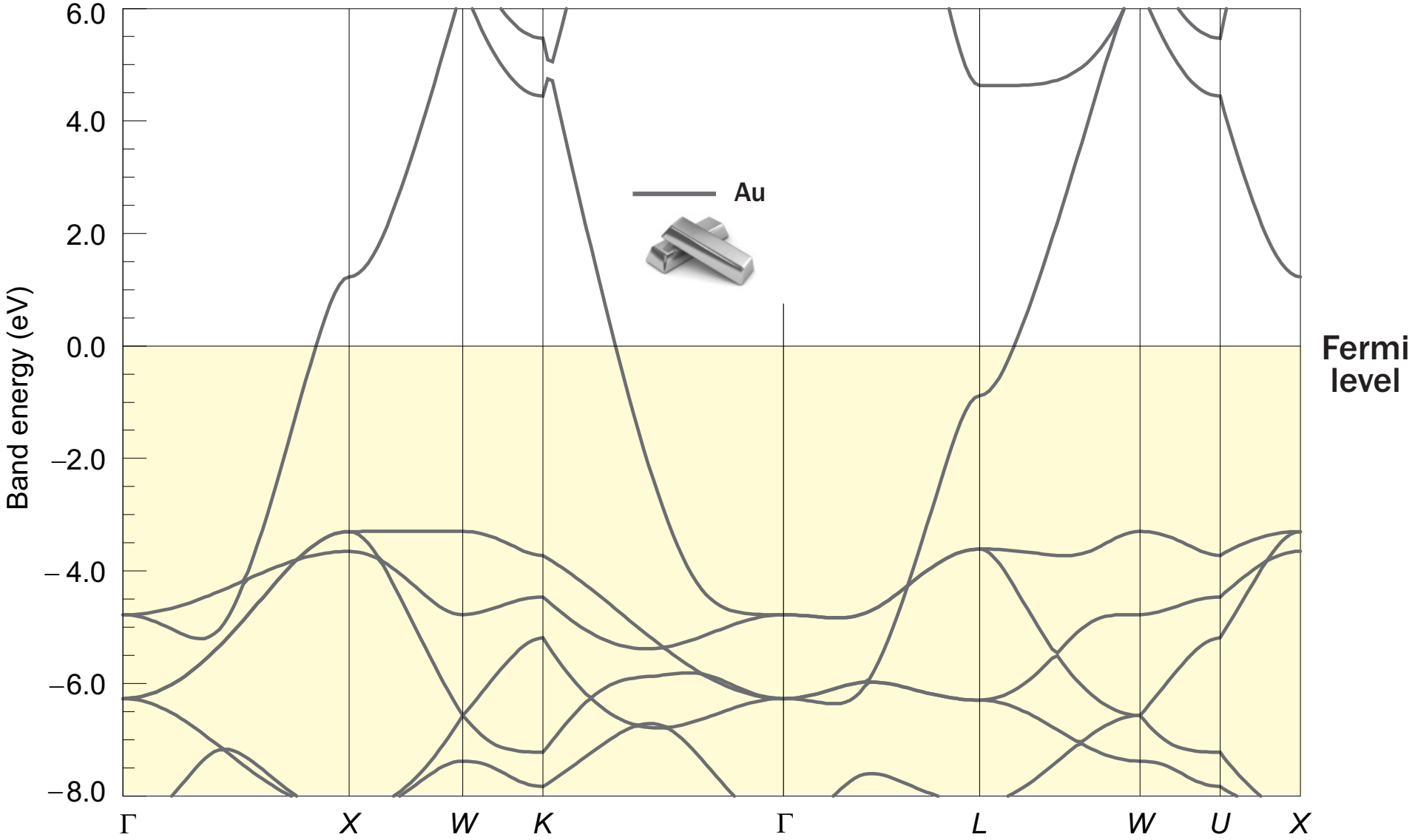
Band structure of silver



Color of metals



What about gold?



What about gold?