Remarks on Teaching Science and on the Nature of Science

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DuPage Division
Illinois Association of School Boards
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We can understand the Universe.

We can understand the Universe.

Nature is reliable, not capricious.

- ▷ Identify and scrutinize assumptions.
- ▷ Hone powers of analysis.
- ▷ Expand capacity for synthesis.

- ▷ Identify and scrutinize assumptions.
- ▷ Hone powers of analysis.
- ▷ Expand capacity for synthesis.

- ▷ *Link cause with effect.*
- ▷ *Search for relevant evidence.*
- ▷ *Seek the truth without self-deception.*

I don't remember a single formula, a single theorem, from three years of college physics. . . . What I do recall . . . is certain ways of thinking, of approaching the world. Physics taught me those, and they have remained with me long after the equations faded. What I'm trying to teach my [creative writing] students, then, are ways of thinking . . . a sensibility.

—Peter Ho Davies, Chicago *Tribune* Books, 1/9/00

THE SENSE OF WONDER

RACHEL CARSON

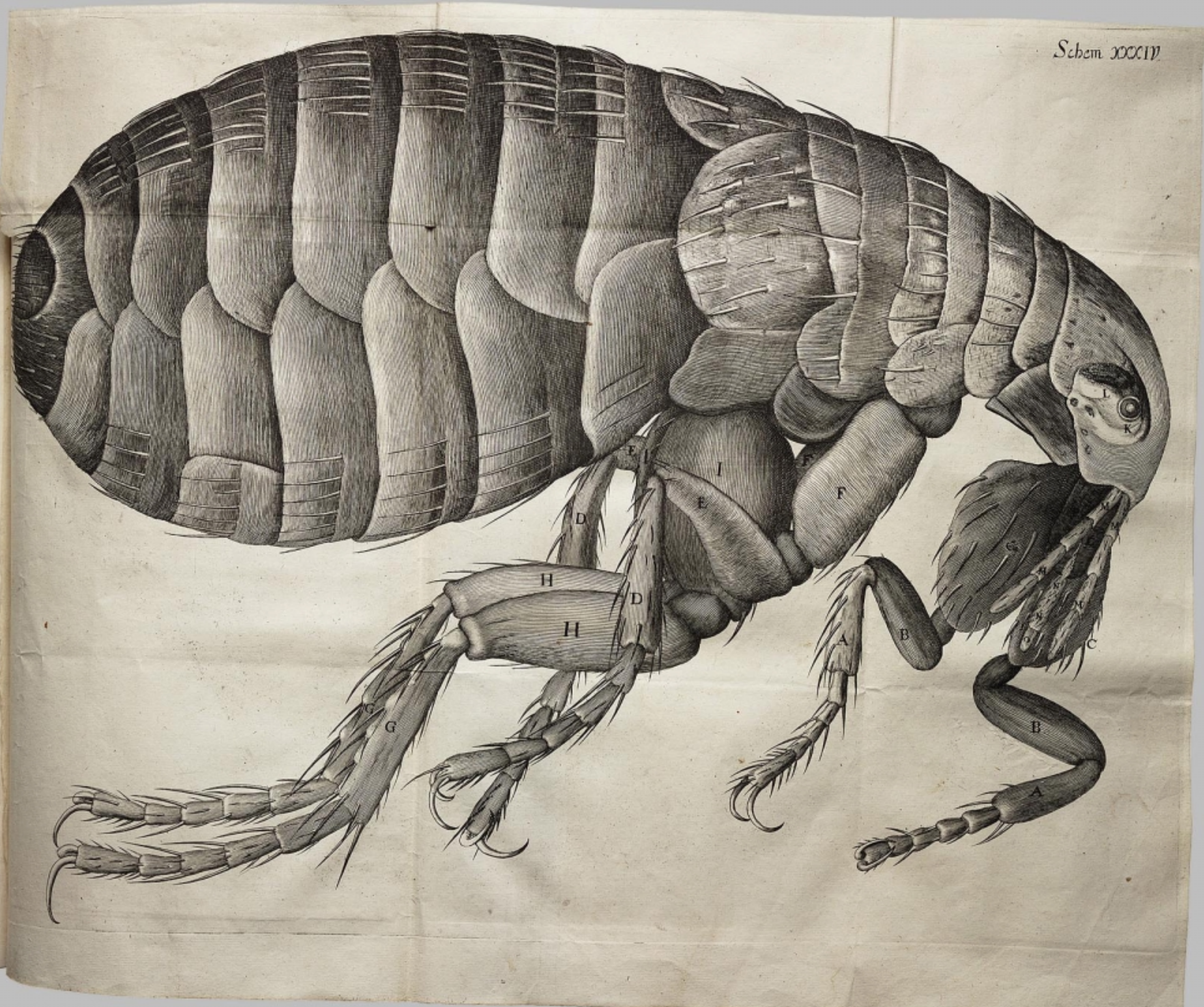
Photographs by CHARLES PRATT and others

Words and pictures to help you keep alive your child's inborn sense of wonder, and renew your own delight in the mysteries of earth, sea and sky

Making Observations

Making Observations

Gathering Specimens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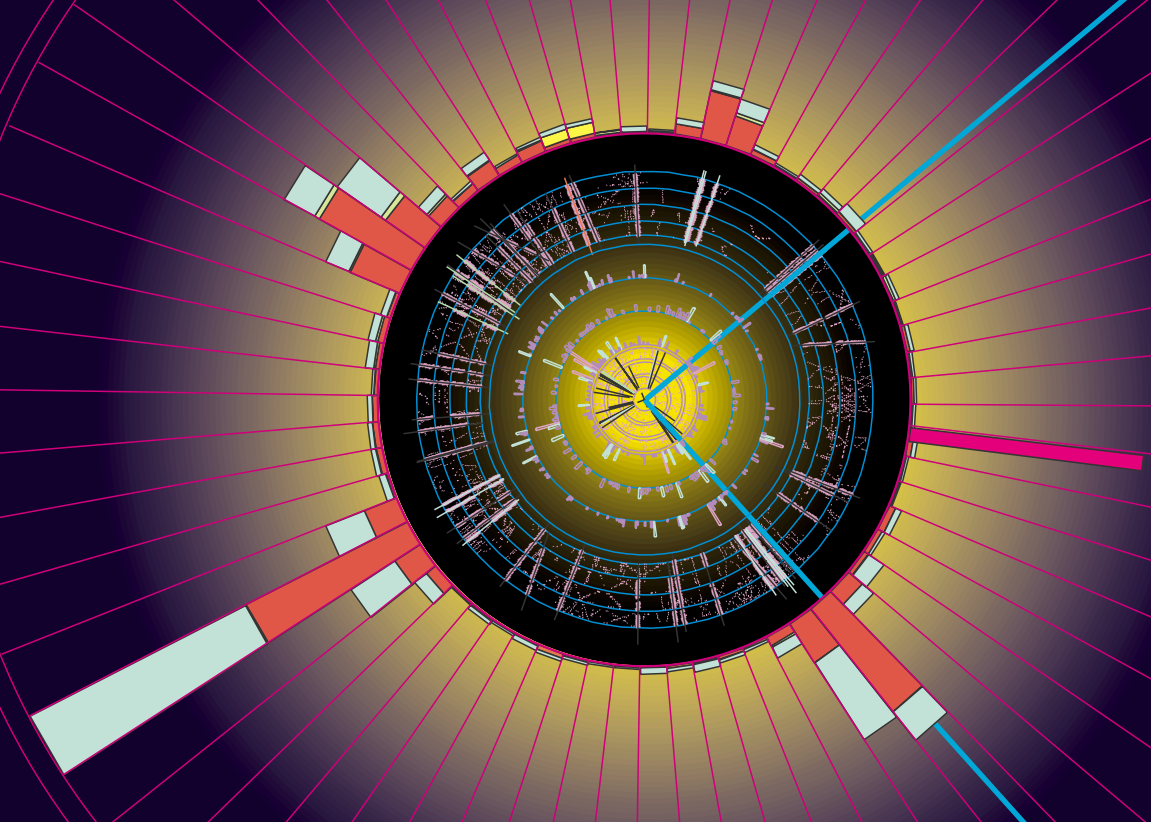


Observing Fermilab's Prairie

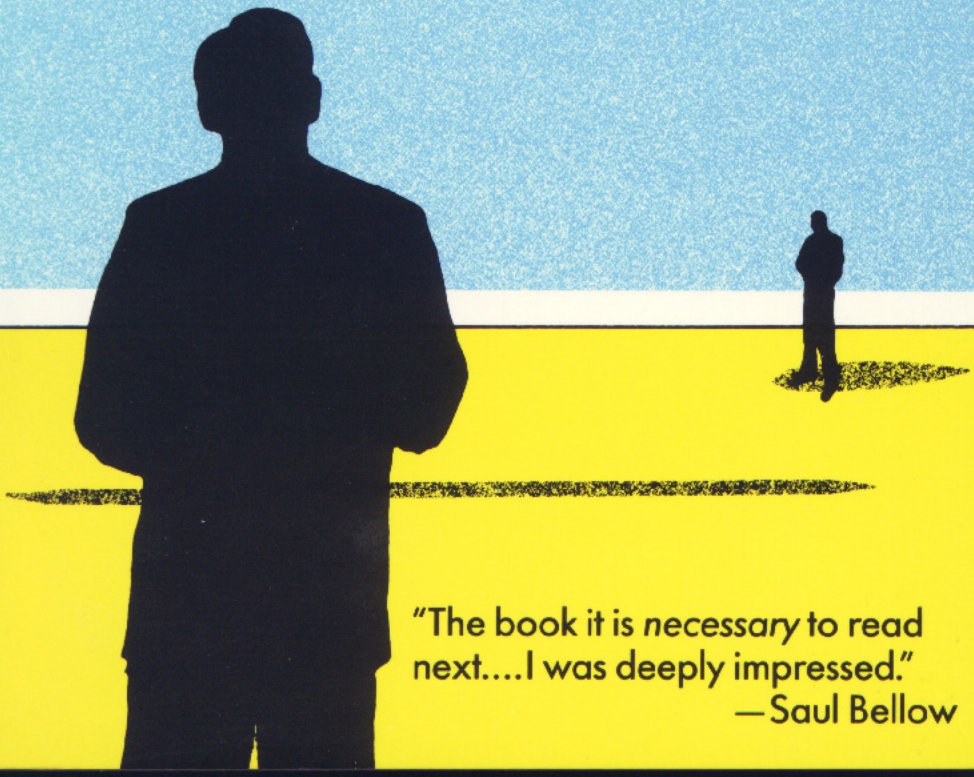
Science is about Nature.

Reality matters.

THE PERIODIC TABLE

by Primo Levi

Translated by Raymond Rosenthal

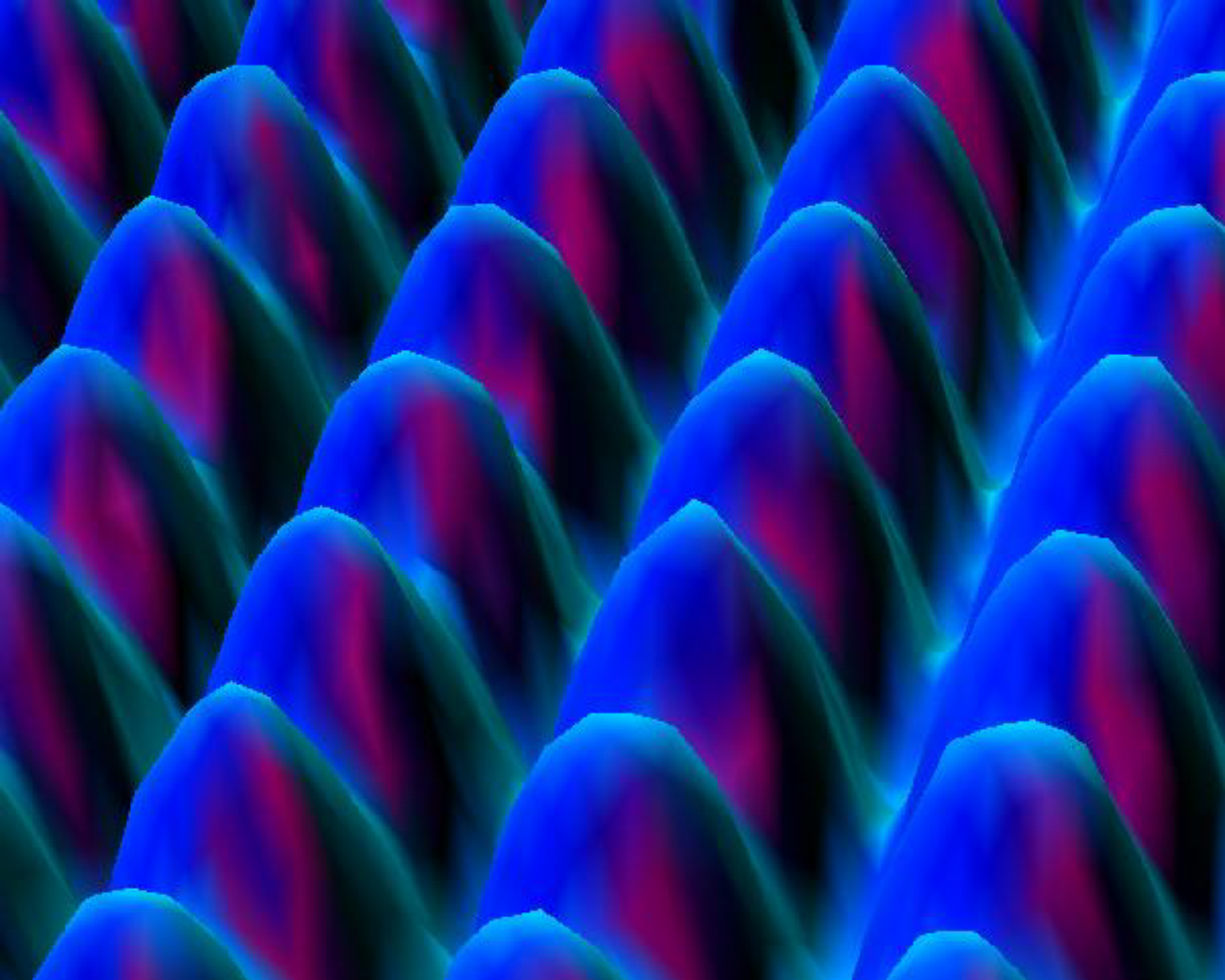


"The book it is *necessary* to read next....I was deeply impressed."
—Saul Bellow

Science enables technology.

Science enables technology.

Technology enables science.



Making Measurements

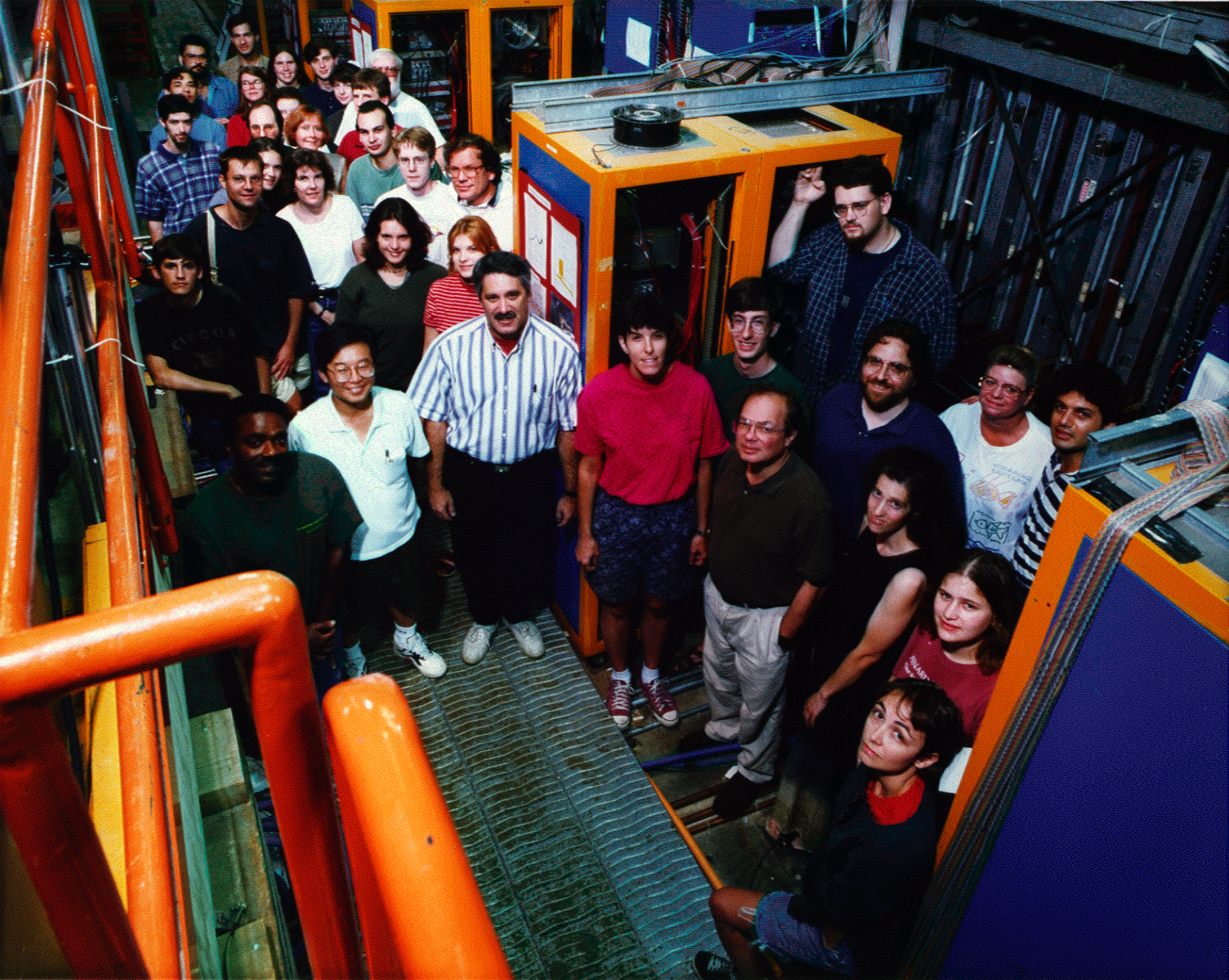
1 H Hydrogen
1 H
3 Li Lithium
4 Be Beryllium
5 B Boron
11 Na Sodium
12 Mg Magnesium
13 Al Aluminum
19 K Potassium
20 Ca Calcium
21 Sc Scandium
Ti
V
24 Cr Chromium
25 Mn Manganese
37 Rb Rubidium
38 Sr Strontium
39 Y Yttrium
Zr
Nb
42 Mo Molybdenum
43 Tc Technetium
55
56
Ta
74 W Tungsten
75 Re Rhenium
Db
106 Sg Seaborgium
107 Bh Bohrium
65 Tb Terbium
66 Dy Dysprosium
67 Ho Holmium
68 Er Erbium
69 Tm Thulium
70 Yb Ytterbium
71 Lu Lutetium
97 Bk Berkelium
98 Cf Californium
99 Es Einsteinium
100 Fm Fermium
101 Md Mendelevium
102 No Nobelium
103 Lr Lawrencium
© copyright roy alexander 2000
patent no. 3581409
Alexander Arrangement of

Doing Experiments

Nullius in Verba!

(Don't take anyone's word for anything!)

People do science.



WebElements: the periodic table on the world-wide web

http://www.webelements.com/

1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
hydrogen **1** H 1.00794(7)																		helium **2** He 4.002602(2)
lithium **3** Li 6.941(2)	beryllium **4** Be 9.012182(3)												boron **5** B 10.811(7)	carbon **6** C 12.0107(8)	nitrogen **7** N 14.00674(7)	oxygen **8** O 15.9994(3)	fluorine **9** F 18.9984032(5)	neon **10** Ne 20.1797(6)
sodium **11** Na 22.989770(2)	magnesium **12** Mg 24.3050(6)												aluminium **13** Al 26.981538(2)	silicon **14** Si 28.0855(3)	phosphorus **15** P 30.973761(2)	sulfur **16** S 32.066(6)	chlorine **17** Cl 35.4527(9)	argon **18** Ar 39.948(1)
potassium **19** K 39.0983(1)	calcium **20** Ca 40.078(4)		scandium **21** Sc 44.955910(8)	titanium **22** Ti 47.867(1)	vanadium **23** V 50.9415(1)	chromium **24** Cr 51.9961(6)	manganese **25** Mn 54.938049(9)	iron **26** Fe 55.845(2)	cobalt **27** Co 58.933200(9)	nickel **28** Ni 58.6934(2)	copper **29** Cu 63.546(3)	zinc **30** Zn 65.39(2)	gallium **31** Ga 69.723(1)	germanium **32** Ge 72.61(2)	arsenic **33** As 74.92160(2)	selenium **34** Se 78.96(3)	bromine **35** Br 79.904(1)	krypton **36** Kr 83.80(1)
rubidium **37** Rb 85.4678(3)	strontium **38** Sr 87.62(1)		yttrium **39** Y 88.90585(2)	zirconium **40** Zr 91.224(2)	niobium **41** Nb 92.90638(2)	molybdenum **42** Mo 95.94(1)		ruthenium **44** Ru 101.07(2)	rhodium **45** Rh 102.90550(2)	palladium **46** Pd 106.42(1)	silver **47** Ag 107.8682(2)	cadmium **48** Cd 112.411(8)	indium **49** In 114.818(3)	tin **50** Sn 118.710(7)	antimony **51** Sb 121.760(1)	tellurium **52** Te 127.60(3)	iodine **53** I 126.90447(3)	xenon **54** Xe 131.29(2)
caesium **55** Cs 132.90545(2)	barium **56** Ba 137.327(7)	**57-70** *	lutetium **71** Lu 174.967(1)		tantalum **73** Ta 180.9479(1)	tungsten **74** W 183.84(1)		osmium **76** Os 190.23(3)	iridium **77** Ir 192.217(3)	platinum **78** Pt 195.078(2)	gold **79** Au 196.96655(2)	mercury **80** Hg 200.59(2)	thallium **81** Tl 204.3833(2)	lead **82** Pb 207.2(1)	bismuth **83** Bi 208.98038(2)	polonium **84** Po [208.9824]		radon **86** Rn [222.0176]
	radium **88** Ra [226.0254]	**89-102** **	lawrencium **103** Lr [262.110]	rutherfordium **104** Rf [261.1089]	dubnium **105** Db [262.1144]	seaborgium **106** Sg [263.1186]	bohrium **107** Bh [264.12]	hassium **108** Hs [265.1306]	meitnerium **109** Mt [268]	ununnilium **110** Uun [269]	unununium **111** Uuu [272]	ununbium **112** Uub [277]		ununquadium **114** Uuq [289]		ununhexium **116** Uuh [289]		ununoctium **118** Uuo [293]

Key:

element name
atomic number
element symbol
1997 atomic weight (mean relative mass)

*lanthanides	lanthanum **57** La 138.9055(2)	cerium **58** Ce 140.116(1)	praseodymium **59** Pr 140.90765(2)	neodymium **60** Nd 144.24(3)		samarium **62** Sm 150.36(3)	europium **63** Eu 151.964(1)	gadolinium **64** Gd 157.25(3)	terbium **65** Tb 158.92534(2)	dysprosium **66** Dy 162.50(3)	holmium **67** Ho 164.93032(2)	erbium **68** Er 167.26(3)	thulium **69** Tm 168.93421(2)	ytterbium **70** Yb 173.04(3)
**actinides	actinium **89** Ac [227.0277]	thorium **90** Th 232.0381(1)	protactinium **91** Pa 231.03588(2)	uranium **92** U 238.0289(1)	neptunium **93** Np [237.0482]	plutonium **94** Pu [244.0642]	americium **95** Am [243.0614]	curium **96** Cm [247.0703]	berkelium **97** Bk [247.0703]	californium **98** Cf [251.0796]	einsteinium **99** Es [252.0830]	fermium **100** Fm [257.0951]	mendelevium **101** Md [258.0984]	nobelium **102** No [259.1011]

Symbols and names: the symbols of the elements, their names, and their spellings are those recommended by IUPAC. After some controversy, the names of elements 101-109 are now confirmed: see Pure & Appl. Chem., 1997, **69**, 2471–2473. Names have not been proposed as yet for the most recently discovered elements 110–112, 114, 116, and 118 so those used here are IUPAC's temporary systematic names: see Pure & Appl. Chem., 1979, **51**, 381–384. In the USA and some other countries, the spellings aluminum and cesium are normal while in the UK and elsewhere the usual spelling is sulphur.
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Atomic weights (mean relative masses): see Pure & Appl. Chem., 1996, **68**, 2339–2359. These are the IUPAC 1995 values. Elements for which the atomic weight is contained within square brackets have no stable nuclides and are represented by one of the element's more important isotopes. However, the three elements thorium, protactinium, and uranium do have characteristic terrestrial abundances and these are the values quoted. The last significant figure of each value is considered reliable to ±1 except where a larger uncertainty is given in parentheses.
©1999 Dr Mark J Winter [University of Sheffield, webelements@sheffield.ac.uk]. For updates to this table see **http://www.shef.ac.uk/chemistry/web-elements/webelements/support/media/pdf/periodic-table.html.** **Version date: 13 July 1999.**

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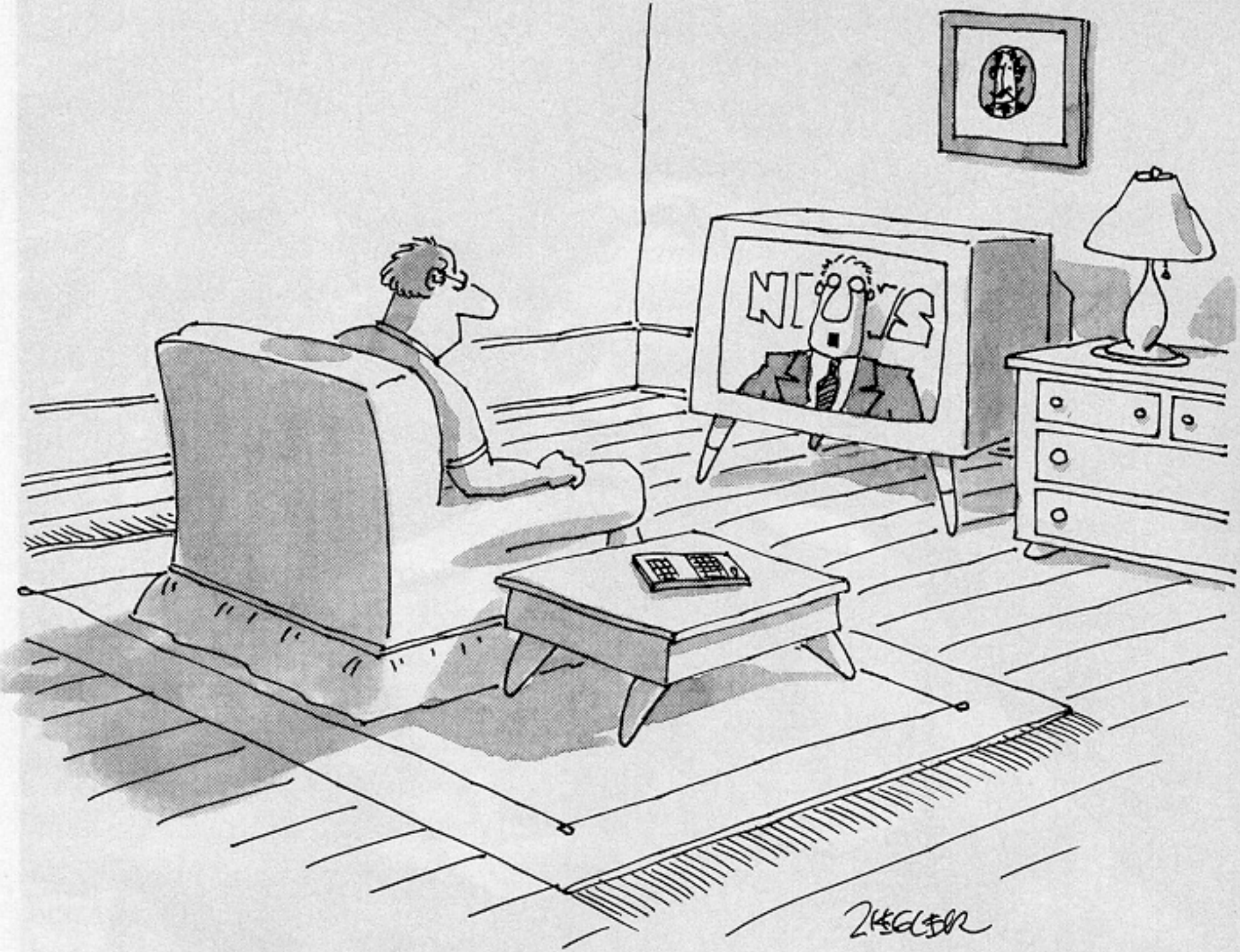


"Scientists confirmed today that everything we know about the structure of the universe is wrongedy-wrong-wrong."

Making Connections

Io stimo più il trovar un vero, benchè di cosa leggiera, ch'l disputar lungamente delle massime questioni senza conseguir verità nissuna.

I attach more value to finding a fact, even about the slightest thing, than to lengthy disputations about the Greatest Questions that fail to lead to any truth whatever.

Intuition is empathy.

Knowing how things will turn out

Learning to hear the poetry of Nature

Science is radically conservative.

Science is radically conservative.

Introduce assumptions reluctantly

Formulate assumptions precisely

Draw consequences widely

Science celebrates doubt.

"the humility of the intellect . . ."

The Importance of Knowing What We Don't Know

Good scientific advice may be frustratingly conditional.

Sometimes . . .

- ▷ We don't know enough to give a straight answer . . .
- ▷ Nature can't be pinned down

Some issues

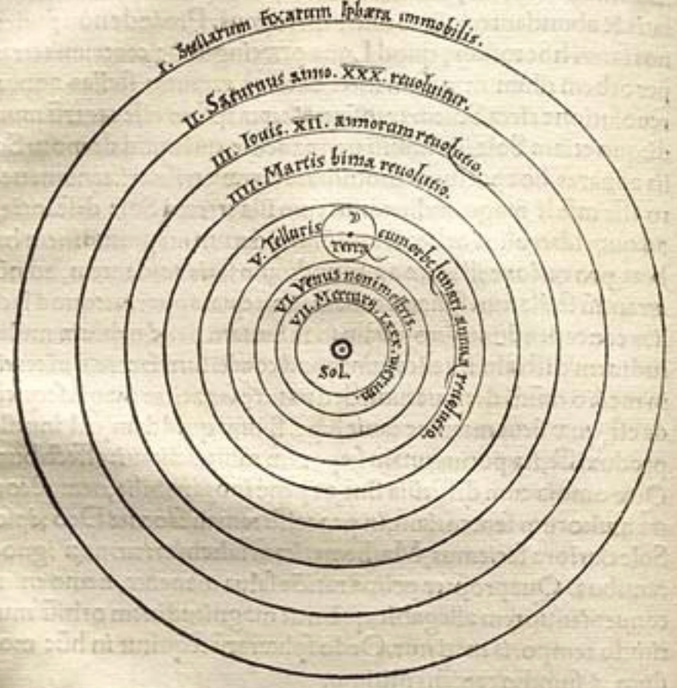
like moral choices

that science

can only *inform*, not *resolve*

Science changes the way we see ourselves, and our world.

net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono mense reducitur. Sextum deniq; locum Mercurius tenet, octuaginta dierum spacio circũ currens. In medio uero omnium residet Sol. Quis enim in hoc



pulcherimo templo lampadem hanc in alio uel meliori loco poneret, quàm unde totum simul possit illuminare? Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem uocant. Trimegistus uisibilem Deum, Sophoclis Electra intuentẽ omnia. Ita profecto tanquam in solio regali Sol residens circum agentem gubernat Astrorum familiam. Tellus quoq; minime fraudatur lunari ministerio, sed ut Aristoteles de animalibus ait, maximã Luna cũ terra cognationẽ habet. Concipit interea à Sole terra, & impregnatur annuo partu. Inuenimus igitur sub hac

hac ordinatione admirandam mundi symmetriam, ac certũ harmoniæ nexum motus & magnitudinis orbium: qualis alio modo reperiri non potest. Hic enim licet animaduertere, nõ segniter contemplanti, cur maior in Ioue progressus & regressus appareat, quàm in Saturno, & minor quàm in Marte: ac rursus maior in Venere quàm in Mercurio. Quodq; frequentior appareat in Saturno talis reciprocatio, quàm in Ioue: rarior adhuc in Marte, & in Venere, quàm in Mercurio. Præterea quòd Saturnus, Iupiter, & Mars acronycti propinquiores sint terræ, quàm circa eorũ occultationem & apparitionem. Maxime uero Mars pernox factus magnitudine Iouem æquare uidetur, colore duntaxat rutilo discretus: illic autem uix inter secundæ magnitudinis stellas inuenitur, sedula obseruatione sectantibus cognitus. Quæ omnia ex eadem causa procedunt, quæ in telluris est motu. Quòd autem nihil eorum apparet in fixis, immensam illorũ arguit celsitudinem, quæ faciat etiam annui motus orbem siue eius imaginem ab oculis euanescere. Quoniã omne uisibile longitudinem distantiæ habet aliquam, ultra quam non amplius spectatur, ut demonstratur in Opticis. Quòd enim à supremo errantium Saturno ad fixarum sphæram adhuc plurimum interest, scintillantia illorum lumina demõstrant. Quo indicio maxime discernuntur à planetis, quodq; inter mota & non mota, maximam oportebat esse differentiam. Tanta nimirum est diuina hæc Opt. Max. fabrica.

De triplici motu telluris demonstratio. Cap. XI.

CVm igitur mobilitati terrenę tot tantaq; errantium syderum consentiant testimonia, iam ipsum motum in summa exponemus, quatenus apparentia per ipsum tanquã hypotesim demonstrentur, quẽ triplicẽ omnino oportet admittere. Primum quem diximus νυχθημερινον à Græcis uocari, diei noctisq; circuitum proprium, circa axem telluris, ab occasu in ortum uergentem, prout in diuersum mundus ferri putatur, æquinoctialem circulum describendo, quem nonnulli æquidialem dicunt, imitantes significationem Græcorum,

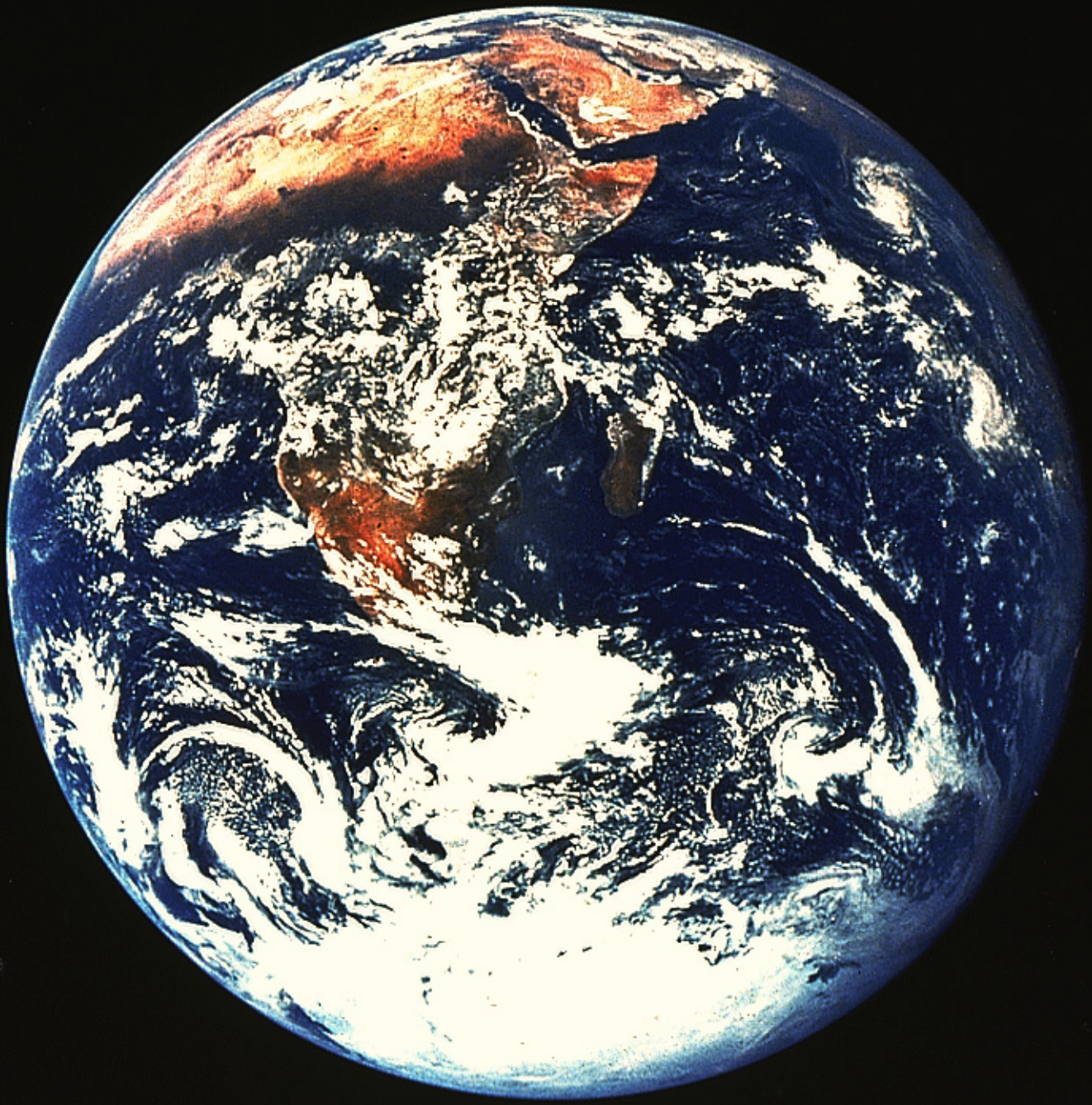
Nicolaus Copernicus. *De Revolutionibus Orbium Cœlestium, Libri VI.* Nuremberg, 1543. THE WARNOCK LIBRARY Octavo™

The Great Lesson of Twentieth-Century Science

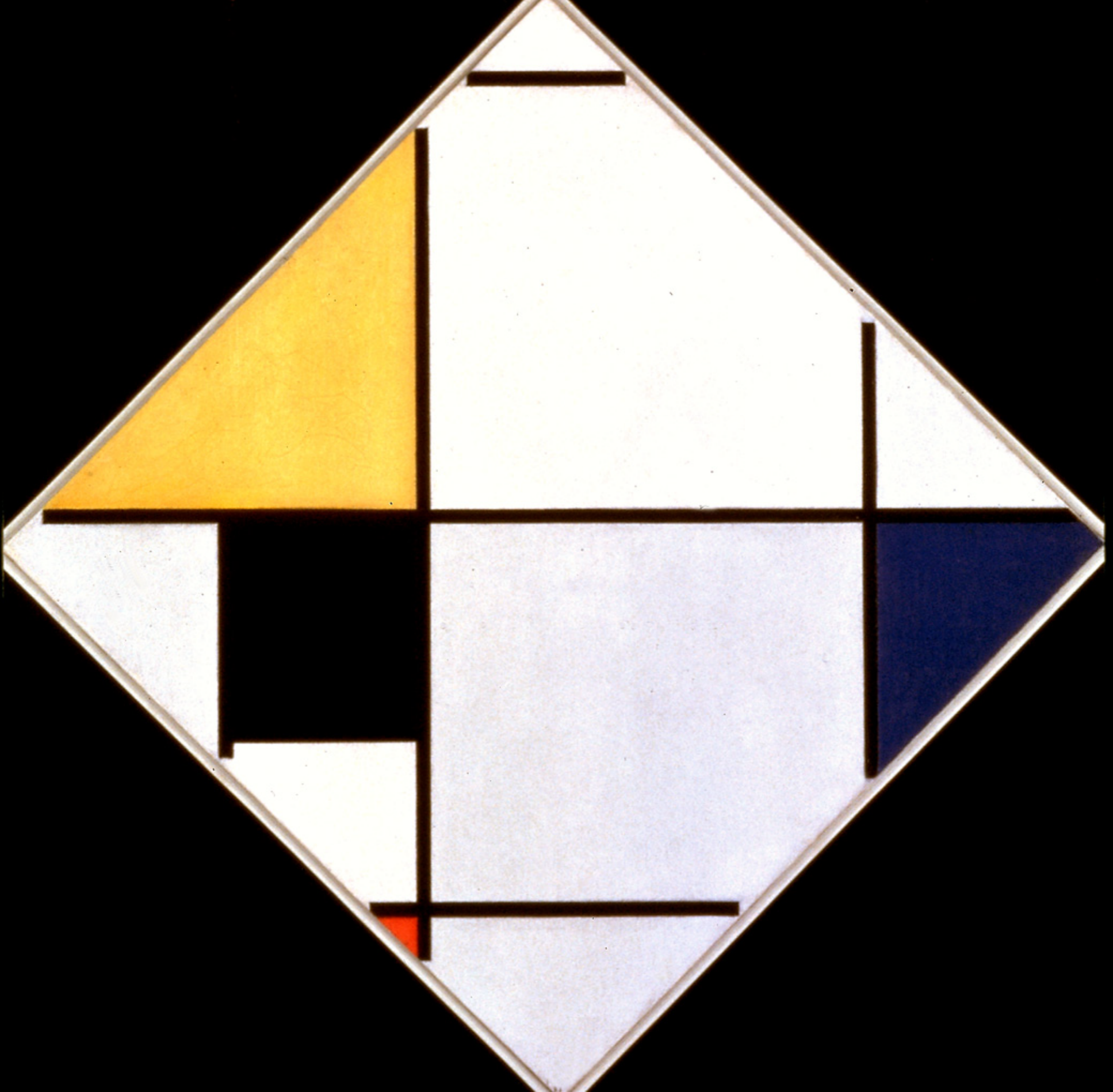
The human scale of space & time

is not privileged for understanding Nature . . .

and may even be disadvantaged



Creativity in Art and Science



Why not?

The Goal of Science . . .

. . . gradually reduce prejudice

—Niels Bohr

[T]here has been one transforming change over this thousand years. It is the adoption of the scientific method: the commitment to experiment, to test every hypothesis. But it is broader than science. It is the open mind, the willingness in all aspects of life to consider possibilities other than the received truth. It is openness to reason.

—Anthony Lewis, New York *Times*, 12/31/99