

## CATEGORIES & CLASSIFICATION

FRANKLIN CALLS THIS THE FURNITURE

WE HAVE PERSUADED OURSELVES

— THERE IS AN OBJECTIVE REALITY,

— WE CAN KNOW ABOUT IT .

— WE CAN SHARE & DEVELOP THIS  
KNOWLEDGE.

SO TO WHAT CATEGORIES OF THINGS

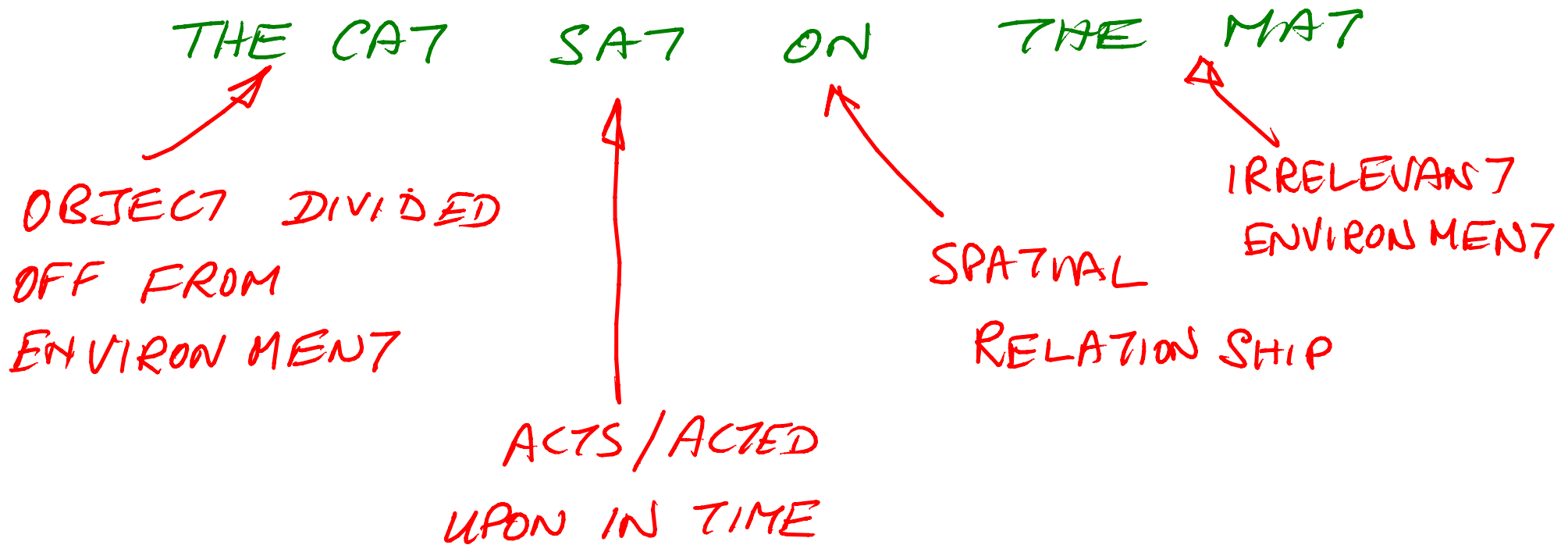
CAN WE APPLY THIS PROCESS ?  
●

# THE WORLD AROUND US LOOKS LIKE A CONTINUUM

- HOW DOES SCIENCE DIVIDE UP REALITY INTO ENTITIES THAT CAN BE INVESTIGATED?
- IT GENERALIZES FROM HUMAN LANGUAGE
  - PARTS OF SPEECH
  - CATEGORIES
- GENERALIZES FROM COMMON SENSE

BOTH OF THESE EVOLVED AS A  
WAY OF KNOWING ABOUT REALITY

FRANKLIN'S APPARENTLY TRIVIAL EXAMPLE  
(PHILOSOPHERS SEEM TO LOVE THESE)



QUARKS ARE CONFINED IN THE PROTON

INFORMATION IS LOST IN A BLACK HOLE  
OR MAYBE IT ISN'T.

# ARISTOTLE'S CATEGORIES

## MODERN SCIENCE?

SUBSTANCE	YES - MAYBE NOT IN PARTICLE PHYSICS
QUANTITY	OK
QUALITY	?
RELATION	} RELATIVE POSITIONS IN SPACE - TIME
PLACE	
TIME	
STATE	- TEMPERATURE, ANGULAR MOMENTUM
ACTION	- A PHOTON TRANSMITS THE ELECTRO MAGNETIC FORCE
AFFECTION	- AN ELECTRON CHANGES ITS MOMENTUM WHEN A PHOTON INTERACTS WITH IT.

DISCUSSES LIGHT

PARTICLES — SUBSTANCE

WAVES — MOTION OF SOMETHING

I THINK HE IS WRONG

— NOT CLEAR THAT ELEMENTARY  
PARTICLES ARE A "SUBSTANCE"

ZERO MASS, ZERO EXTENT

— WAVE NATURE JUST COMES FROM  
FACT THAT WAVE FN HAS PHASE

$$\psi = A e^{i\phi}$$

OK FOR MACROSCOPIC → NOT QUANTUM

THERE IS AN ISSUE CONCERNING LOCALITY

→ LATER

• SCIENCE ESSENTIALLY ADAPTS EVERYDAY LANGUAGE IN TERMS OF PARTS OF SPEECH THIS WORKS FOR SCIENCE OF FAMILIAR WORLD

BIOLOGY

CHEMISTRY

MACRO-PHYSICS

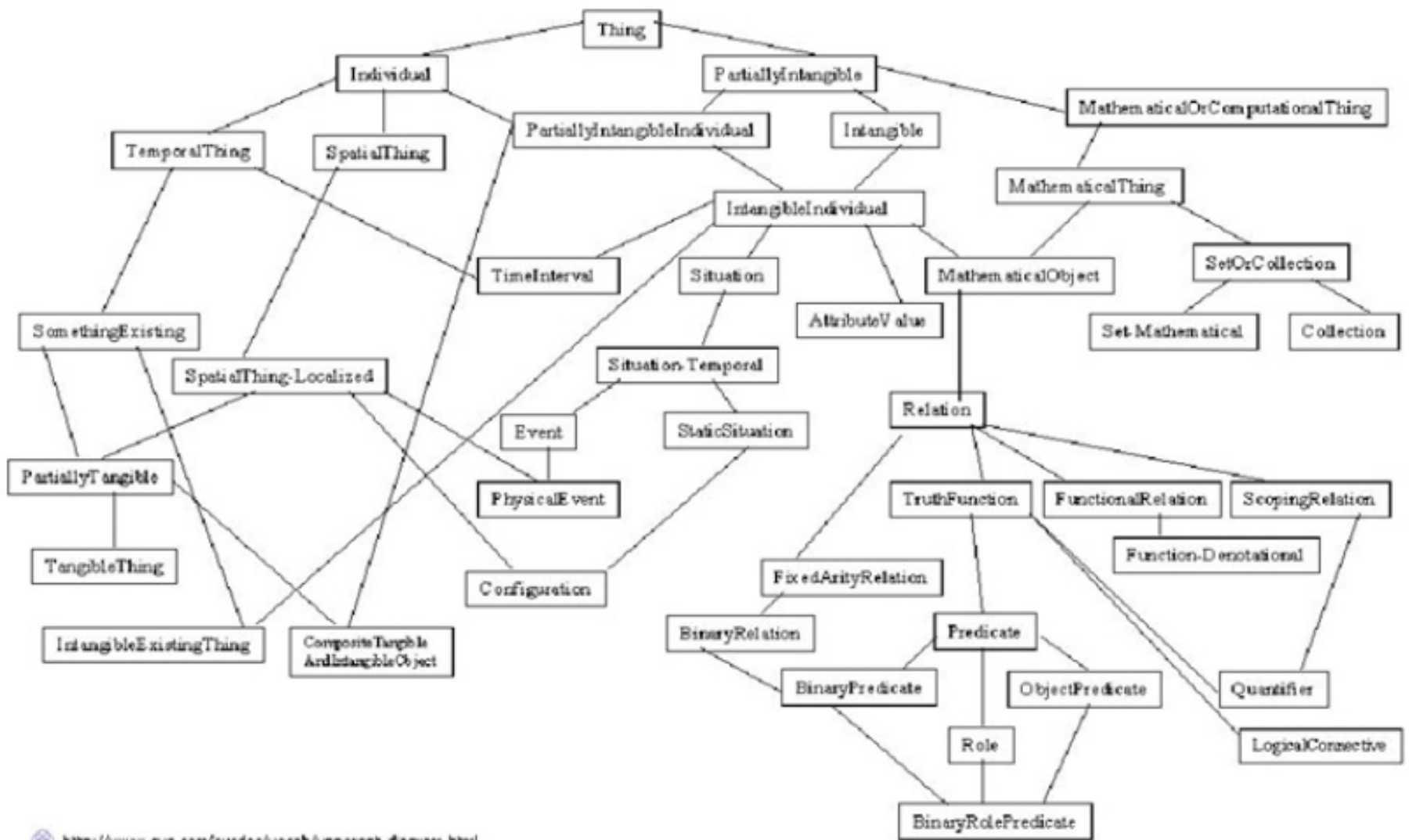
WHEN WE MOVE AWAY FROM  
WE START TO BE AWARE OF AN INCOMPLETE MAPPING  
REALITY ↔ EVERYDAY LANGUAGE

eg " WAVE ↔ PARTICLE "

" INFINITE INFLATION "

" WAVE FUNCTION OF THE UNIVERSE "

→ MATHEMATICS



UNDERSTANDING HOW WE MAP THE  
STRUCTURE OF REALITY → LANGUAGE

→ EXPERT SYSTEMS → ARTIFICIAL INTELLIGENCE

# CLASSIFICATION

- CLASSIFICATION OF OBJECTS IN THE WORLD AROUND US → CENTRAL TO SCIENCE
- AGAIN IT GROWS OUT OF HOW WE USE NATURAL LANGUAGE
- WRONG CLASSIFICATION LEADS TO CONFUSION CONCERNING WHAT IS ACTUALLY WORTH DISCUSSING → PSEUDO SCIENCE
- HILARIOUS EXAMPLE FROM BORGES

OTHER BORGES } "LIBRARY OF BABEL"  
PHYSICS / MATHS } "GARDEN OF FORKING-PATHS"



EARLY PHASE OF A NEW SCIENTIFIC

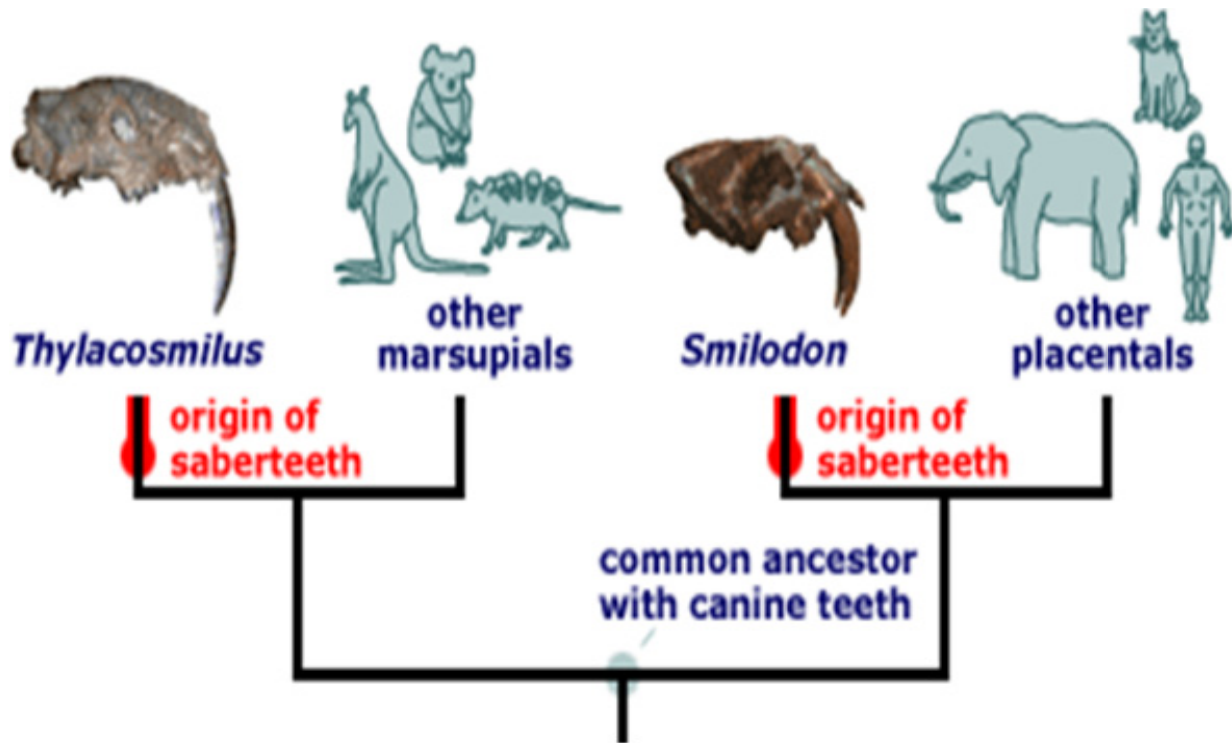
STUDY → DECIDE ON CLASSIFICATION

→ UNDERSTAND RELATIONSHIP

→ BUILD THEORY

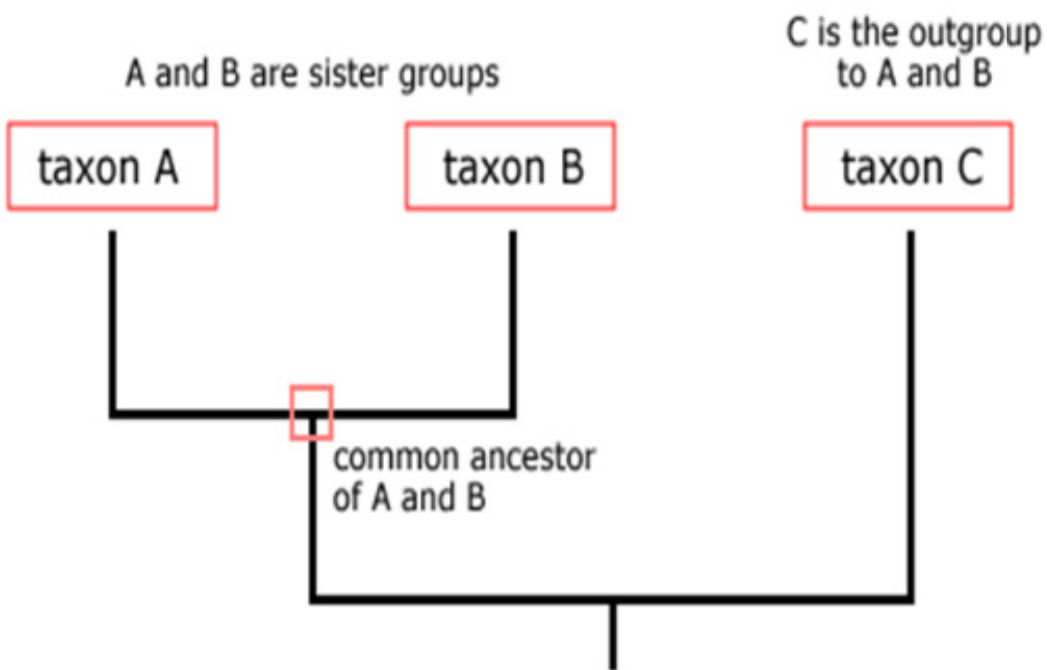
→ MAKE & TEST PREDICTIONS

IN TERMS OF ELEMENTS  
OF CLASSIFICATIONS

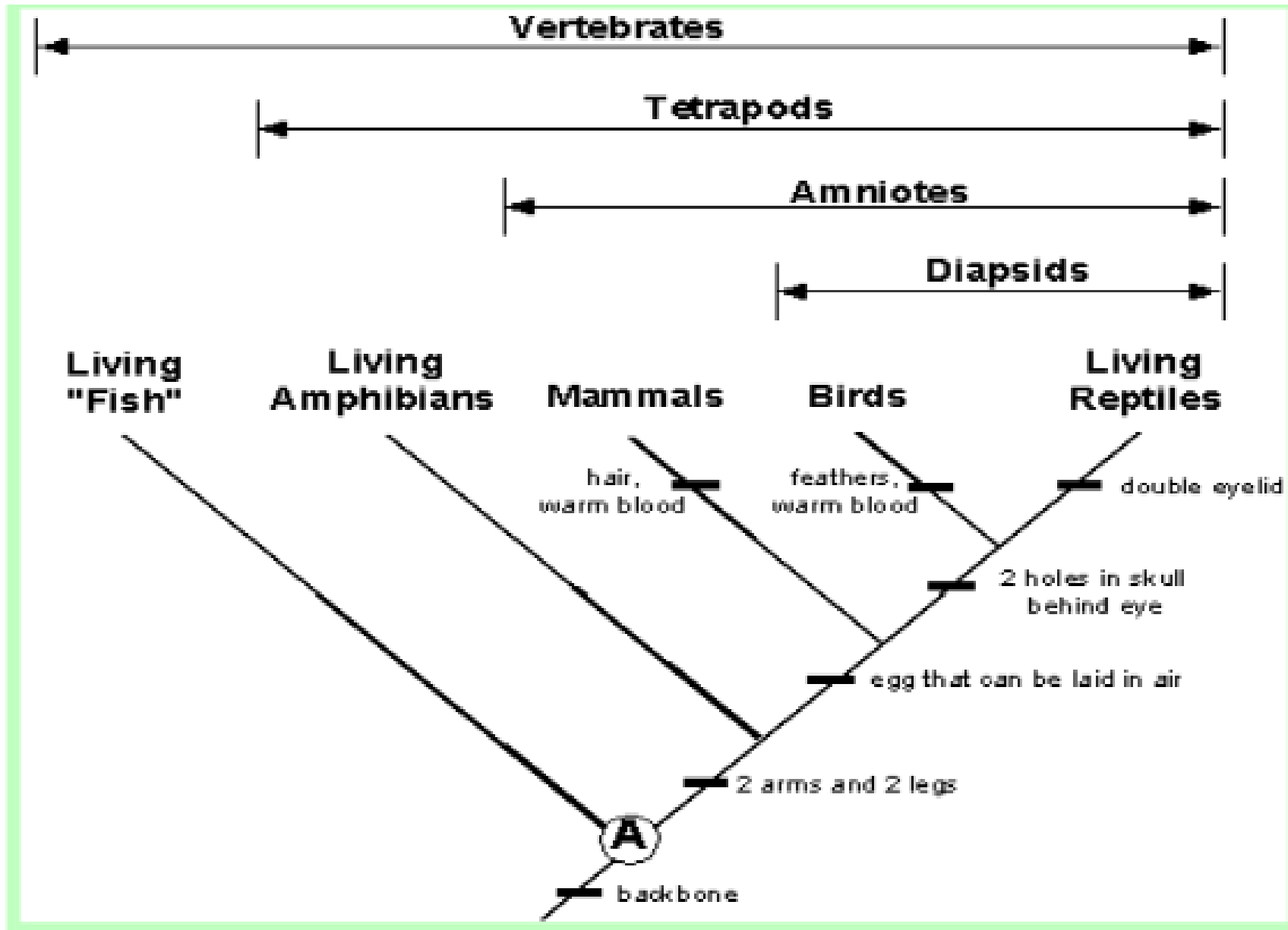


CLADE DIAGRAMS  
 USED TO CLASSIFY  
 HOW DIFFERENT  
 ANIMALS RELATED

• WHICH TAXONOMIC  
 FEATURES COME  
 FROM SHARED  
 INHERITANCE

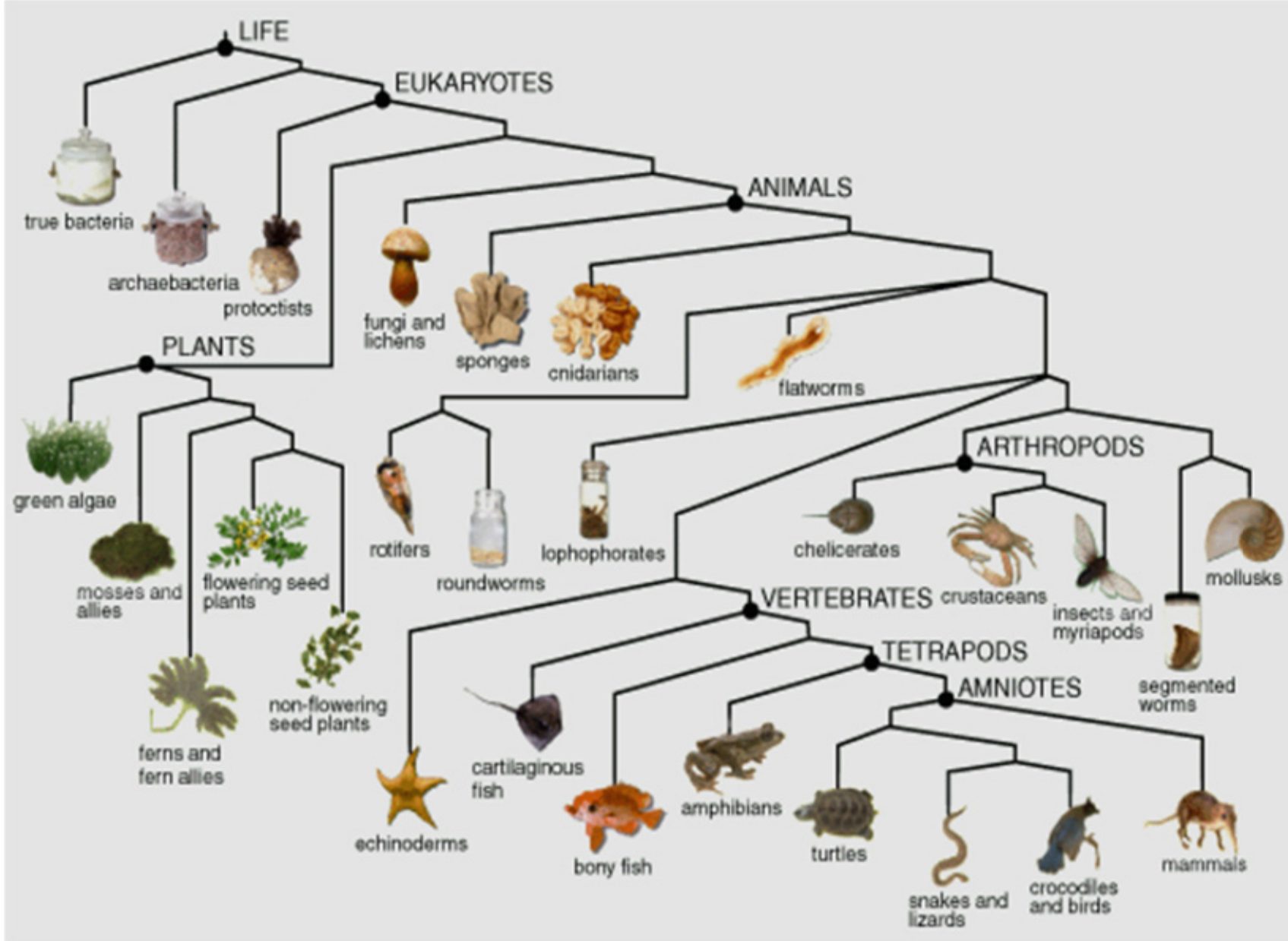


• WHICH DO NOT  
 COME FROM CLOSE  
 RELATIONSHIP



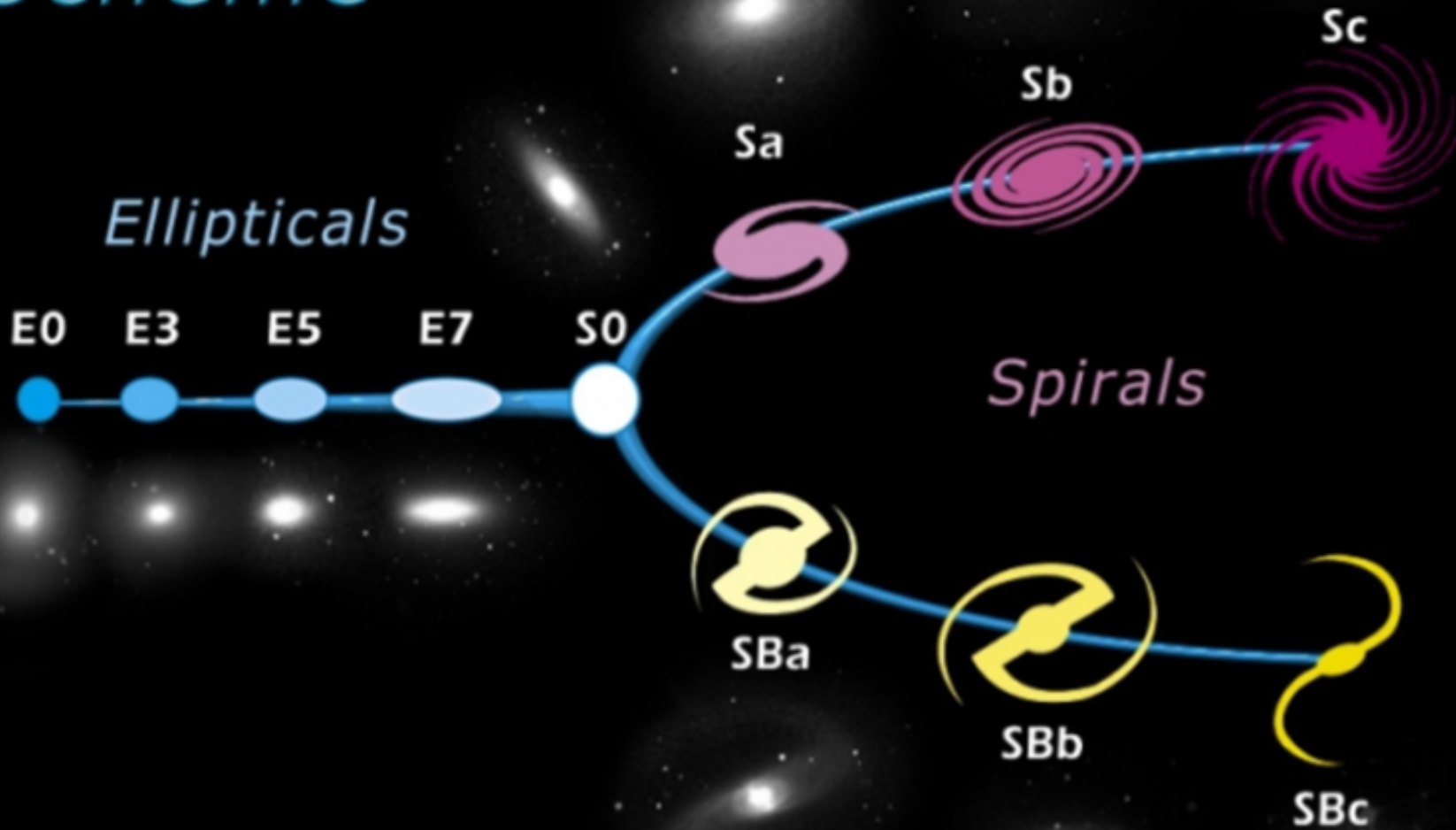
FINE GRAINED CLASSIFICATION

SPECIES → LARGER CLASSES → EVOLUTION



TREE OF LIFE → EVOLUTION → INFERENCE TO THE BEST EXPLANATION

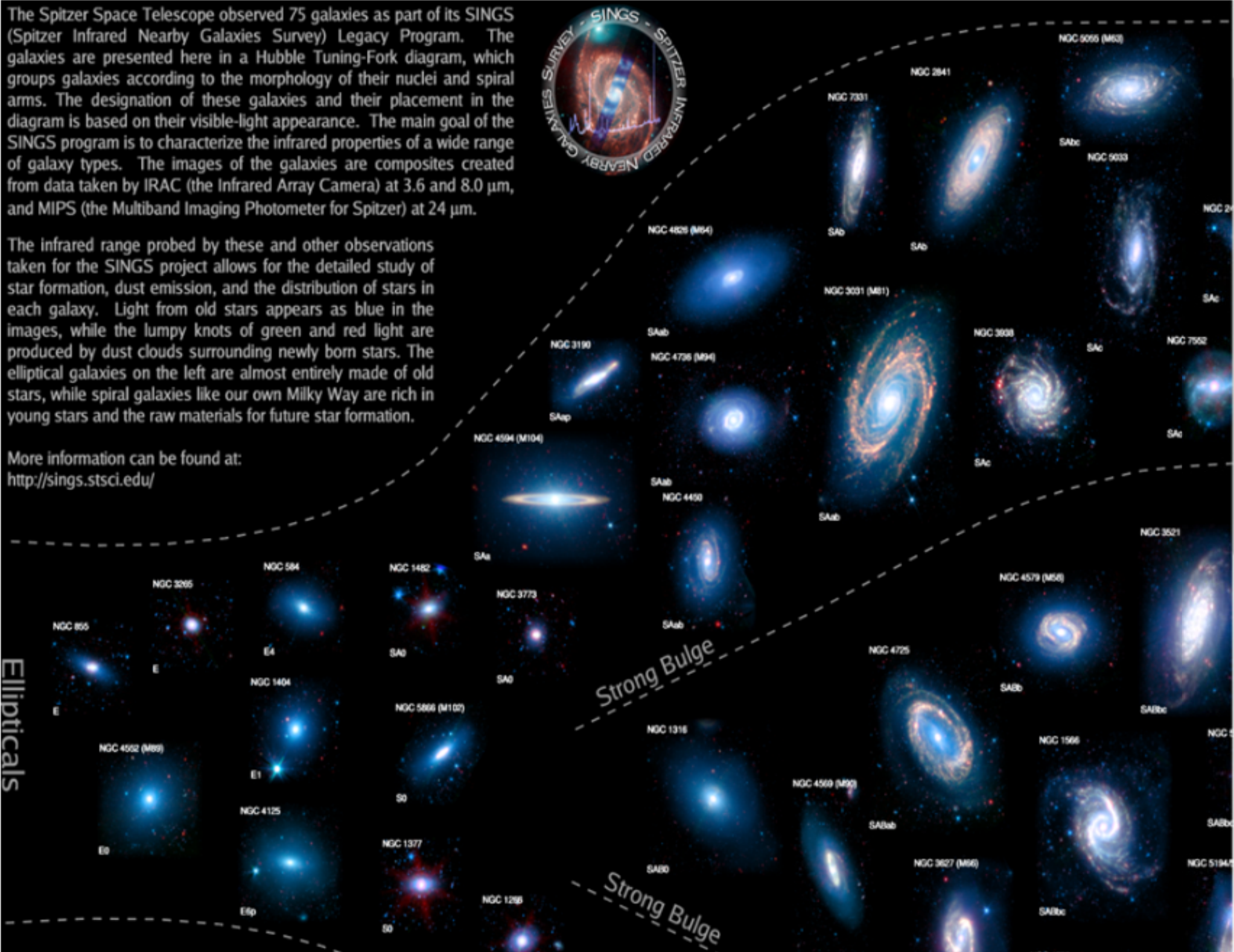
# Edwin Hubble's Classification Scheme



The Spitzer Space Telescope observed 75 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning-Fork diagram, which groups galaxies according to the morphology of their nuclei and spiral arms. The designation of these galaxies and their placement in the diagram is based on their visible-light appearance. The main goal of the SINGS program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composites created from data taken by IRAC (the Infrared Array Camera) at 3.6 and 8.0  $\mu\text{m}$ , and MIPS (the Multiband Imaging Photometer for Spitzer) at 24  $\mu\text{m}$ .

The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.

More information can be found at:  
<http://sings.stsci.edu/>



# CHOOSING THE WRONG CLASSIFICATION

DIRECT OBSERVATION OF ATOMIC NATURE OF MATTER

PRE-ACCELERATOR	MASS ( $\text{MeV}/c^2$ )	
ELECTRON	0.5	LIGHT
PROTONS	1000	HEAVY
NEUTRON	1000	HEAVY
" $\mu$ -MESON"	106	MEDIUM
ACCELERATOR		
$\pi$ -MESON	140	MEDIUM
K-MESON	493	MEDIUM
$\Delta^{++}$	1230	HEAVY
$N^*$	1440	HEAVY

➔ CLASSIFY BY MASS ??

**LIGHT I = 1 MESONS**

$\pi^0$	111
$\pi^+$	211
$\alpha_0(980)^0$	9000111
$\alpha_0(980)^+$	9000211
$\pi(1300)^0$	100111
$\pi(1300)^+$	100211
$\alpha_0(1450)^0$	10111
$\alpha_0(1450)^+$	10211
$\pi(1800)^0$	9010111
$\pi(1800)^+$	9010211
$\rho(770)^0$	113
$\rho(770)^+$	213
$b_1(1235)^0$	10113
$b_1(1235)^+$	10213
$\alpha_1(1260)^0$	20113
$\alpha_1(1260)^+$	20213
$\pi_1(1400)^0$	9000113
$\pi_1(1400)^+$	9000213
$\rho(1450)^0$	100113
$\rho(1450)^+$	100213
$\pi_1(1600)^0$	9010113
$\pi_1(1600)^+$	9010213
$\alpha_1(1640)^0$	9020113
$\alpha_1(1640)^+$	9020213
$\rho(1700)^0$	30113
$\rho(1700)^+$	30213
$\rho(1900)^0$	9030113
$\rho(1900)^+$	9030213
$\rho(2150)^0$	9040113
$\rho(2150)^+$	9040213
$\alpha_2(1320)^0$	115
$\alpha_2(1320)^+$	215
$\pi_2(1670)^0$	10115
$\pi_2(1670)^+$	10215
$\alpha_2(1700)^0$	9000115
$\alpha_2(1700)^+$	9000215
$\pi_2(2100)^0$	9010115
$\pi_2(2100)^+$	9010215
$\rho_3(1690)^0$	117
$\rho_3(1690)^+$	217
$\rho_3(1990)^0$	9000117
$\rho_3(1990)^+$	9000217
$\rho_3(2250)^0$	9010117
$\rho_3(2250)^+$	9010217
$\alpha_4(2040)^0$	119
$\alpha_4(2040)^+$	219

**LIGHT I = 0 MESONS**  
(u $\bar{u}$ , d $\bar{d}$ , and s $\bar{s}$  Admixtures)

$\eta$	221
$\eta'(958)$	331
$f_0(600)$	9000221
$f_0(980)$	9010221
$\eta(1295)$	100221
$f_0(1370)$	10221
$\eta(1405)$	9020221
$\eta(1475)$	100331
$f_0(1500)$	9030221
$f_0(1710)$	10331
$\eta(1760)$	9040221
$f_0(2020)$	9050221
$f_0(2100)$	9060221
$f_0(2200)$	9070221
$\eta(2225)$	9080221
$\omega(782)$	223
$\phi(1020)$	333
$h_1(1170)$	10223
$f_1(1285)$	20223
$h_1(1380)$	10333
$f_1(1420)$	20333
$\omega(1420)$	100223
$f_1(1510)$	9000223
$h_1(1595)$	9010223
$\omega(1650)$	30223
$\phi(1680)$	100333
$f_2(1270)$	225
$f_2(1430)$	9000225
$f_2'(1525)$	335
$f_2(1565)$	9010225
$f_2(1640)$	9020225
$\eta_2(1645)$	10225
$f_2(1810)$	9030225
$\eta_2(1870)$	10335
$f_2(1910)$	9040225
$f_2(1950)$	9050225
$f_2(2010)$	9060225
$f_2(2150)$	9070225
$f_2(2300)$	9080225
$f_2(2340)$	9090225
$\omega_3(1670)$	227
$\phi_3(1850)$	337
$f_4(2050)$	229
$f_4(2220)$	9000229
$f_4(2300)$	9010229

**STRANGE MESONS**

$K_L^0$	130
$K_S^0$	310
$K^0$	311
$K^+$	321
$K_S^*(800)^0$	9000311
$K_S^*(800)^+$	9000321
$K_S^*(1430)^0$	10311
$K_S^*(1430)^+$	10321
$K(1460)^0$	100311
$K(1460)^+$	100321
$K(1830)^0$	9010311
$K(1830)^+$	9010321
$K_S^*(1950)^0$	9020311
$K_S^*(1950)^+$	9020321
$K^*(892)^0$	313
$K^*(892)^+$	323
$K_1(1270)^0$	10313
$K_1(1270)^+$	10323
$K_1(1400)^0$	20313
$K_1(1400)^+$	20323
$K^*(1410)^0$	100313
$K^*(1410)^+$	100323
$K_1(1650)^0$	9000313
$K_1(1650)^+$	9000323
$K^*(1680)^0$	30313
$K^*(1680)^+$	30323
$K_2^*(1430)^0$	315
$K_2^*(1430)^+$	325
$K_2(1580)^0$	9000315
$K_2(1580)^+$	9000325
$K_2(1770)^0$	10315
$K_2(1770)^+$	10325
$K_2(1820)^0$	20315
$K_2(1820)^+$	20325
$K_2^*(1980)^0$	9010315
$K_2^*(1980)^+$	9010325
$K_2(2250)^0$	9020315
$K_2(2250)^+$	9020325
$K_3^*(1780)^0$	317
$K_3^*(1780)^+$	327
$K_3(2320)^0$	9010317
$K_3(2320)^+$	9010327
$K_4^*(2045)^0$	319
$K_4^*(2045)^+$	329
$K_4(2500)^0$	9000319
$K_4(2500)^+$	9000329

**CHARMED MESONS**

$D^+$	411
$D^0$	421
$D_S^*(2400)^+$	10411
$D_S^*(2400)^0$	10421
$D^*(2010)^+$	413
$D^*(2007)^0$	423
$D_1(2420)^+$	10413
$D_1(2420)^0$	10423
$D_1(H)^+$	20413
$D_1(2430)^0$	20423
$D_2^*(2460)^+$	415
$D_2^*(2460)^0$	425
$D_s^+$	431
$D_{s0}^*(2317)^+$	10431
$D_s^+$	433
$D_{s1}(2536)^+$	10433
$D_{s1}(2460)^+$	20433
$D_{s2}^*(2573)^+$	435

**BOTTOM MESONS**

$B^0$	511
$B^+$	521
$B_S^0$	10511
$B_S^+$	10521
$B^0$	513
$B^{*+}$	523
$B_1(L)^0$	10513
$B_1(L)^+$	10523
$B_1(H)^0$	20513
$B_1(H)^+$	20523
$B_2^0$	515
$B_2^+$	525
$B_s^0$	531
$B_{s0}^0$	10531
$B_s^0$	533
$B_{s1}(L)^0$	10533
$B_{s1}(H)^0$	20533
$B_{s2}^0$	535
$B_c^+$	541
$B_{c0}^+$	10541
$B_c^+$	543
$B_{c1}(L)^+$	10543
$B_{c1}(H)^+$	20543
$B_{c2}^+$	545

**cc MESONS**

$\eta_c(1S)$	441
$\chi_{c0}(1P)$	10441
$\eta_c(2S)$	100441
$J/\psi(1S)$	443
$h_{c1}(1P)$	10443
$\chi_{c1}(1P)$	20443
$\psi(2S)$	100443
$\psi(3770)$	30443
$\psi(4040)$	9000443
$\psi(4160)$	9010443
$\psi(4415)$	9020443
$\chi_{c0}(2P)$	445
$\chi_{c2}(2P)$	100445

**bb MESONS**

$\eta_b(1S)$	551
$\chi_{b0}(1P)$	10551
$\eta_b(2S)$	100551
$\chi_{b0}(2P)$	110551
$\eta_b(3S)$	200551
$\chi_{b0}(3P)$	210551
$\Upsilon(1S)$	553
$h_b(1P)$	10553
$\chi_{b1}(1P)$	20553
$\Upsilon_1(1D)$	30553
$\Upsilon(2S)$	100553
$h_b(2P)$	110553
$\chi_{b1}(2P)$	120553
$\Upsilon_1(2D)$	130553
$\Upsilon(3S)$	200553
$h_b(3P)$	210553
$\chi_{b2}(3P)$	220553
$\Upsilon(4S)$	300553
$\Upsilon(10860)$	9000553
$\Upsilon(11020)$	9010553
$\chi_{b2}(1P)$	555
$\eta_{b2}(1D)$	10555
$\Upsilon_2(1D)$	20555
$\chi_{b2}(2P)$	100555
$\eta_{b2}(2D)$	110555
$\Upsilon_2(2D)$	120555
$\chi_{b2}(3P)$	200555
$\Upsilon_3(1D)$	557
$\Upsilon_3(2D)$	100557

**LIGHT BARYONS**

$p$	2212
$n$	2112
$\Delta^{++}$	2224
$\Delta^+$	2214
$\Delta^0$	2114
$\Delta^-$	1114

**STRANGE BARYONS**

$\Lambda$	3122
$\Sigma^+$	3222
$\Sigma^0$	3212
$\Sigma^-$	3112
$\Sigma^{*+}$	3224 <sup>d</sup>
$\Sigma^{*0}$	3214 <sup>d</sup>
$\Sigma^{*-}$	3114 <sup>d</sup>
$\Xi^0$	3322
$\Xi^-$	3312
$\Xi^{*0}$	3324 <sup>d</sup>
$\Xi^{*-}$	3314 <sup>d</sup>
$\Xi_b^+$	3334

**CHARMED BARYONS**

$\Lambda_c^+$	4122
$\Sigma_c^{*+}$	4222
$\Sigma_c^+$	4212
$\Sigma_c^0$	4112
$\Sigma_c^{*+}$	4224
$\Sigma_c^{*0}$	4214
$\Sigma_c^0$	4114
$\Xi_c^+$	4232
$\Xi_c^0$	4132
$\Xi_c^{*+}$	4322
$\Xi_c^{*0}$	4312
$\Xi_c^0$	4324
$\Xi_c^{*0}$	4314
$\Omega_c^0$	4332
$\Omega_c^+$	4334
$\Xi_{cc}^+$	4412
$\Xi_{cc}^{*+}$	4422
$\Xi_{cc}^0$	4414
$\Xi_{cc}^{*0}$	4424
$\Omega_{cc}^+$	4432
$\Omega_{cc}^{*+}$	4434
$\Omega_{cc}^+$	4444

**PENTAQUARKS**

$\Theta^+$	9221132
$\Phi^{*-}$	9331122

**BOTTOM BARYONS**

$\Lambda_b^0$	5122
$\Sigma_b^-$	5112
$\Sigma_b^0$	5212
$\Sigma_b^+$	5222
$\Sigma_b^{*0}$	5114
$\Sigma_b^{*+}$	5214
$\Sigma_b^{*+}$	5224
$\Xi_b^-$	5132
$\Xi_b^0$	5232
$\Xi_b^{*-}$	5312
$\Xi_b^{*0}$	5322
$\Xi_b^{*+}$	5314
$\Xi_b^0$	5324
$\Omega_b^-$	5332
$\Omega_b^0$	5334
$\Xi_{bc}^0$	5142
$\Xi_{bc}^{*0}$	5242
$\Xi_{bc}^0$	5412
$\Xi_{bc}^{*0}$	5424
$\Omega_{bc}^0$	5342
$\Omega_{bc}^0$	5432
$\Omega_{bc}^{*0}$	5434
$\Omega_{bc}^0$	5442
$\Omega_{bc}^{*0}$	5444
$\Xi_{bb}^-$	5512
$\Xi_{bb}^0$	5522
$\Xi_{bb}^{*0}$	5514
$\Xi_{bb}^0$	5524
$\Omega_{bb}^-$	5532
$\Omega_{bb}^0$	5534
$\Xi_{bbc}^0$	5542
$\Xi_{bbc}^0$	5544
$\Omega_{bbc}^0$	5554

IF I COULD REMEMBER THE NAMES OF ALL THESE PARTICLES, THEN

COULD BE A ZOOLOGIST - E. FERMI



MODERN NOMENCLATURE STILL REFLECTS  
CLASSIFICATION BY MASS

LEPTON — LIGHT

MESON — MIDDLE

BARYON — HEAVY

OTHER POSSIBLE CLASSIFICATIONS

STRENGTH OF INTERACTION

ANGULAR MOMENTUM

ELECTRIC CHARGE

OTHER QUANTUM NUMBERS

STRANGENESS

HYPERCHARGE

⋮

CHEMISTRY → CLASSIFY BY MASS → QUANTUM THEORY  
 ELECTRON ORBITS  
 STRENGTH OF INTERACTION

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1 <b>H</b> Hydrogen 1.008	Atomic # Symbol Name Weight	<b>C</b> Solid																2 <b>He</b> Helium 4.002602
3 <b>Li</b> Lithium 6.94	4 <b>Be</b> Beryllium 9.012182	<b>Hg</b> Liquid																
11 <b>Na</b> Sodium 22.989...	12 <b>Mg</b> Magnesium 24.305	<b>H</b> Gas																
		<b>Rf</b> Unknown																
19 <b>K</b> Potassium 39.0983	20 <b>Ca</b> Calcium 40.078	21 <b>Sc</b> Scandium 44.955...	22 <b>Ti</b> Titanium 47.867	23 <b>V</b> Vanadium 50.9415	24 <b>Cr</b> Chromium 51.9961	25 <b>Mn</b> Manganese 54.938...	26 <b>Fe</b> Iron 55.845	27 <b>Co</b> Cobalt 58.933...	28 <b>Ni</b> Nickel 58.6934	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.38	31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.63	33 <b>As</b> Arsenic 74.92160	34 <b>Se</b> Selenium 78.96	35 <b>Br</b> Bromine 79.904	36 <b>Kr</b> Krypton 83.798	
37 <b>Rb</b> Rubidium 85.4678	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.90585	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.90638	42 <b>Mo</b> Molybdenum 95.96	43 <b>Tc</b> Technetium (98)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.90...	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.8682	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.710	51 <b>Sb</b> Antimony 121.760	52 <b>Te</b> Tellurium 127.60	53 <b>I</b> Iodine 126.90...	54 <b>Xe</b> Xenon 131.293	
55 <b>Cs</b> Caesium 132.90...	56 <b>Ba</b> Barium 137.327	57-71	72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.94...	74 <b>W</b> Tungsten 183.84	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.23	77 <b>Ir</b> Iridium 192.217	78 <b>Pt</b> Platinum 195.084	79 <b>Au</b> Gold 196.96...	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.38	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.98...	84 <b>Po</b> Polonium (209)	85 <b>At</b> Astatine (210)	86 <b>Rn</b> Radon (222)	
87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	89-103	104 <b>Rf</b> Rutherfordium (261)	105 <b>Db</b> Dubnium (268)	106 <b>Sg</b> Seaborgium (271)	107 <b>Bh</b> Bohrium (272)	108 <b>Hs</b> Hassium (270)	109 <b>Mt</b> Meitnerium (276)	110 <b>Ds</b> Darmstadtium (281)	111 <b>Rg</b> Roentgenium (280)	112 <b>Cn</b> Copernicium (285)	113 <b>Uut</b> Ununtrium (284)	114 <b>Fl</b> Flerovium (289)	115 <b>Uup</b> Ununpentium (288)	116 <b>Lv</b> Livermorium (293)	117 <b>Uus</b> Ununseptium (294)	118 <b>Uuo</b> Ununoctium (294)	

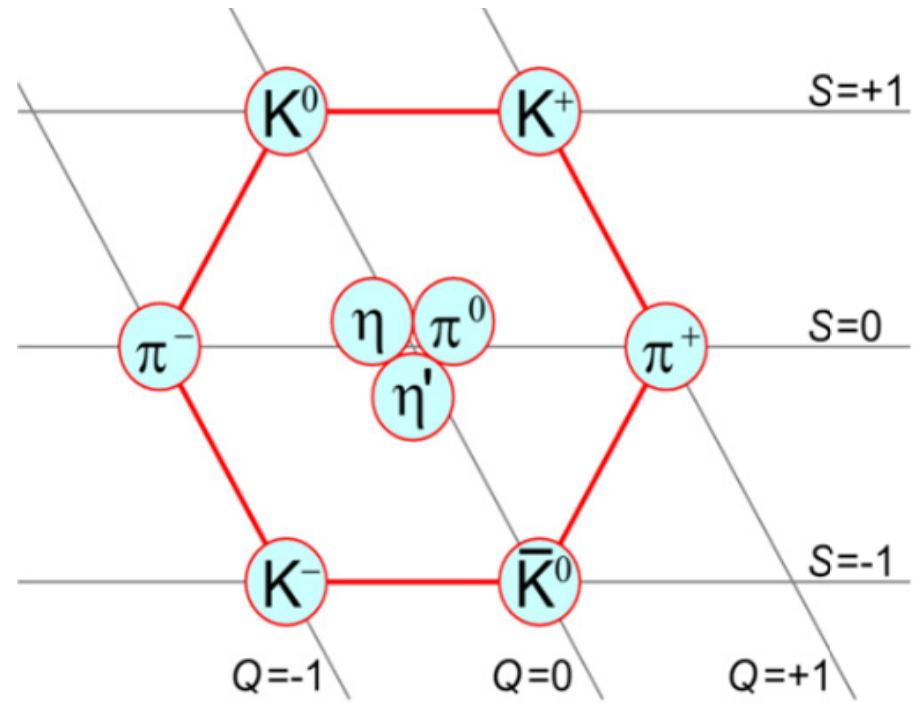
For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

Periodic Table Design & Interface Copyright © 1997 Michael Dayah Ptable.com Last updated Jul 31, 2013

57 <b>La</b> Lanthanum 138.90...	58 <b>Ce</b> Cerium 140.116	59 <b>Pr</b> Praseodymium 140.90...	60 <b>Nd</b> Neodymium 144.242	61 <b>Pm</b> Promethium (145)	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.964	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.92...	66 <b>Dy</b> Dysprosium 162.500	67 <b>Ho</b> Holmium 164.93...	68 <b>Er</b> Erbium 167.259	69 <b>Tm</b> Thulium 168.93...	70 <b>Yb</b> Ytterbium 173.054	71 <b>Lu</b> Lutetium 174.9668
89 <b>Ac</b> Actinium (227)	90 <b>Th</b> Thorium 232.03...	91 <b>Pa</b> Protactinium 231.03...	92 <b>U</b> Uranium 238.02...	93 <b>Np</b> Neptunium (237)	94 <b>Pu</b> Plutonium (244)	95 <b>Am</b> Americium (243)	96 <b>Cm</b> Curium (247)	97 <b>Bk</b> Berkelium (247)	98 <b>Cf</b> Californium (251)	99 <b>Es</b> Einsteinium (252)	100 <b>Fm</b> Fermium (257)	101 <b>Md</b> Mendelevium (258)	102 <b>No</b> Nobelium (259)	103 <b>Lr</b> Lawrencium (262)

# GEHL-MANN/NE'EMAN — THE EIGHTFOLD WAY

IF YOU CLASSIFY THE MESONS BY  
 ELECTRIC CHARGE  
 STRANGENESS  
 FORGET ABOUT MASS  
 THEY FALL INTO  
 A "GROUP" OF 8 + "GROUP" OF 1



$$SU(3) \quad 3 \otimes \bar{3} = 8 + 1$$

IRREDUCIBLE

REPRESENTATION

ADJOINT

# SU(3) IRREDUCIBLE REPRESENTATION

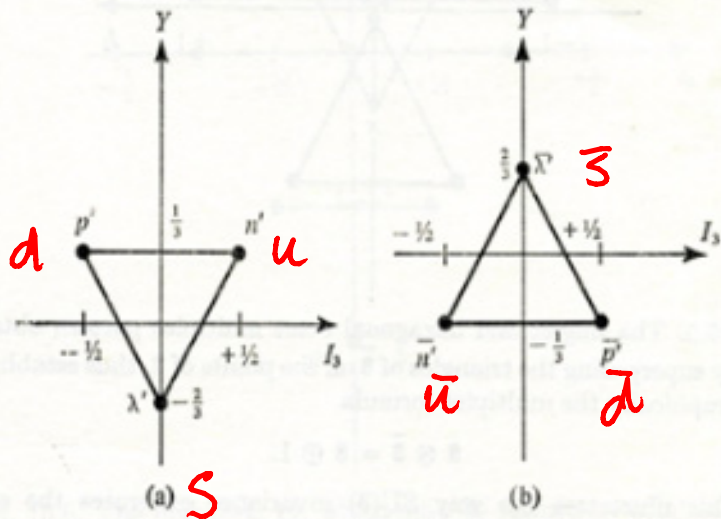


FIG. 15.4. A graphical representation of the basic SU(3) triplets; (a) the quark,  $\mathbf{3}$ , and (b) the anti-quark,  $\bar{\mathbf{3}}$ . If the scale is chosen the same for  $F_3 = I_3$  and  $F_8 = \frac{\sqrt{3}}{2} Y$ , they are represented by equilateral triangles.

# TRANSFORMATIONS AMONG 3 FUNDAMENTAL ENTITIES

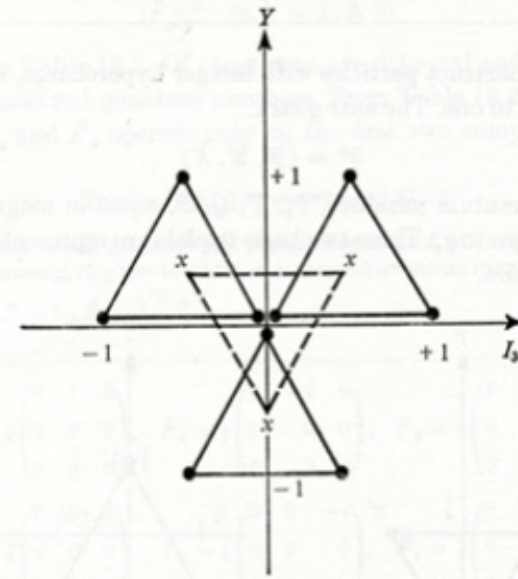


FIG. 15.5. The singlet and hexagonal octet multiplet pattern obtained by superposing the triangles of  $\bar{\mathbf{3}}$  on the points of  $\mathbf{3}$ , thus establishing graphically the multiplet formula

$$\mathbf{3} \otimes \bar{\mathbf{3}} = \mathbf{8} \oplus \mathbf{1}.$$

$$\mathbf{3} \otimes \mathbf{3} \otimes \mathbf{3} = \mathbf{1} \oplus 2 \times \mathbf{8} \oplus \mathbf{10}.$$

Since for these, by Table 15.3,  $B = \frac{1}{3} + \frac{1}{3} + \frac{1}{3} = 1$  the 8 of this construction satisfactorily accounts for the eight-fold pattern of  $B = 1$ , spin  $\frac{1}{2}\hbar$

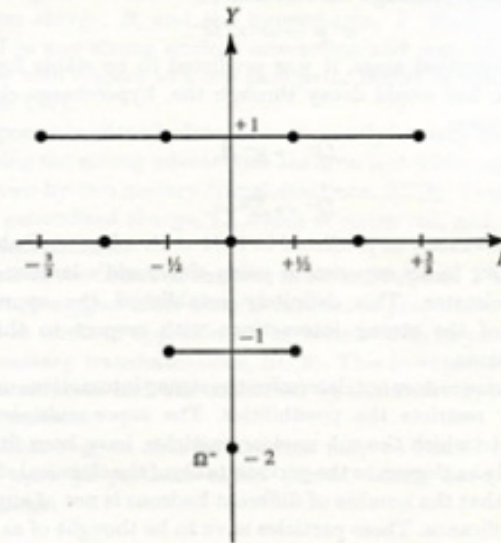


FIG. 15.6. The decuplet,  $\mathbf{10}$ , which may be formed by combining three basic quark triplets,  $\mathbf{3}$ . Nine particles corresponding to the three upper rows, with  $B = 1$  and spin  $\frac{3}{2}\hbar$ , were found by 1962. The tenth particle,  $\Omega^-$ , corresponding to the lower vertex was discovered in 1964.

$$\mathbf{3} \otimes \bar{\mathbf{3}} = \mathbf{8} \oplus \mathbf{1}$$

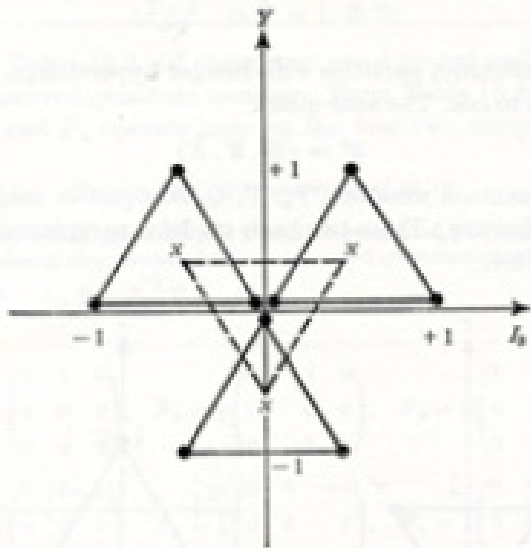
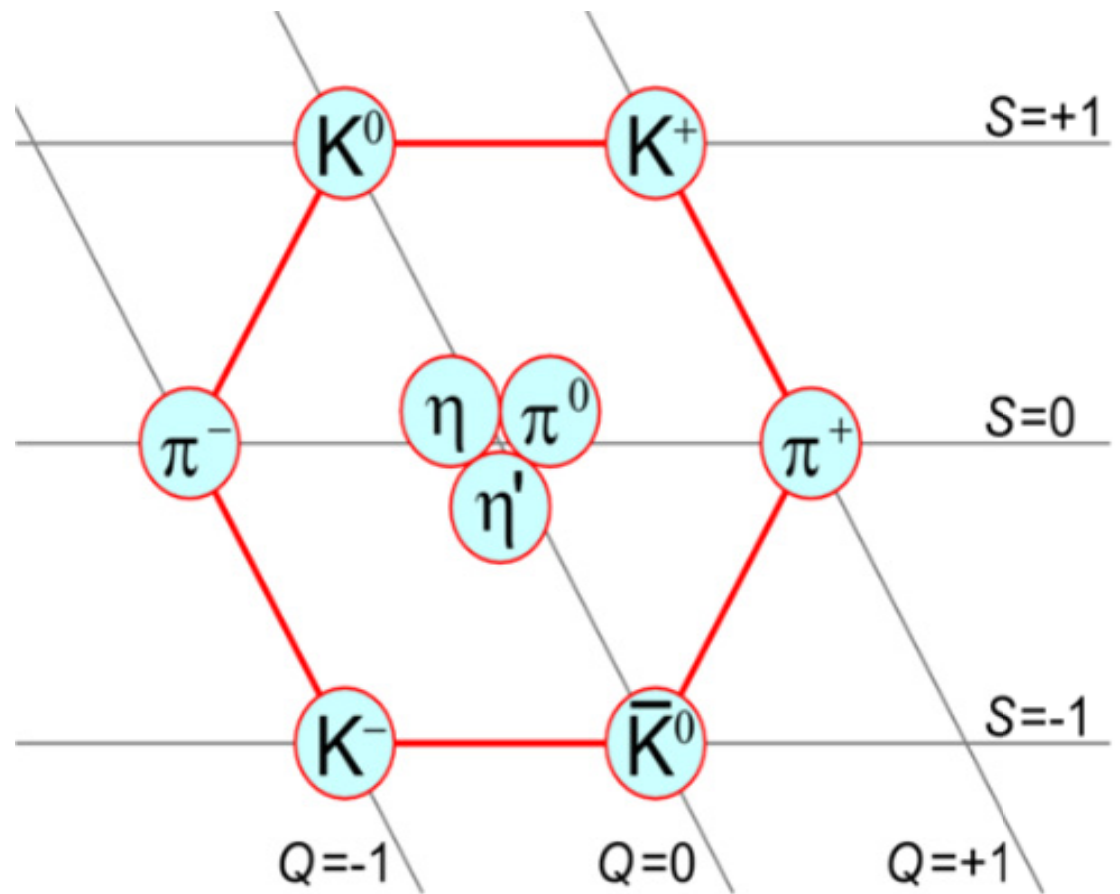
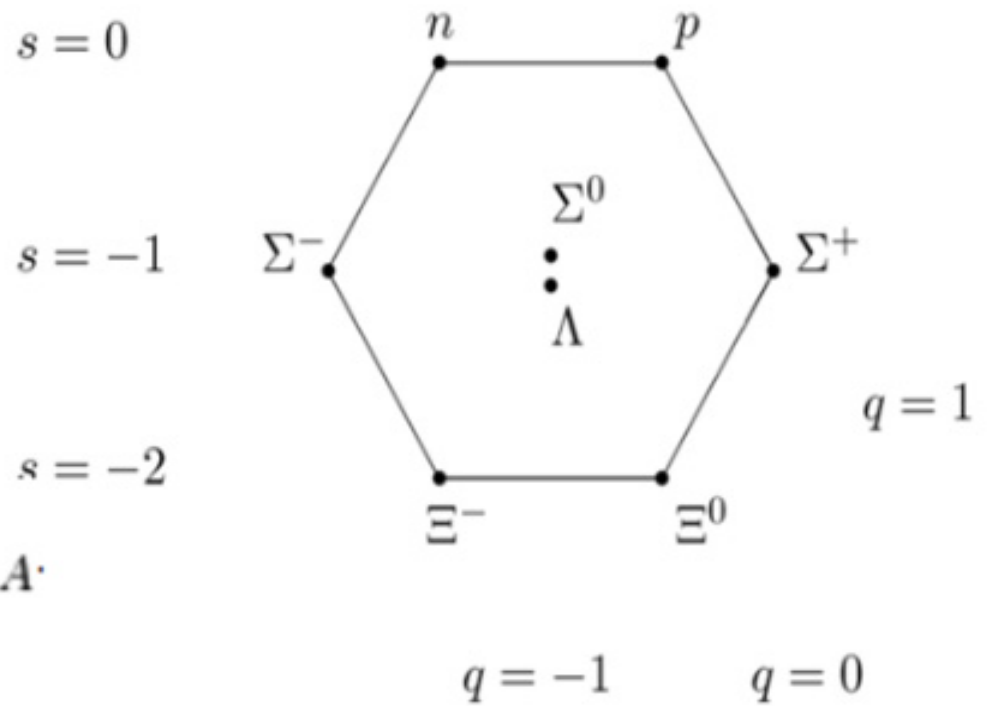


FIG. 15.5. The singlet and hexagonal octet multiplet pattern obtained by superposing the triangles of  $\bar{\mathbf{3}}$  on the points of  $\mathbf{3}$ , thus establishing graphically the multiplet formula

$$\mathbf{3} \otimes \bar{\mathbf{3}} = \mathbf{8} \oplus \mathbf{1}$$



$$\mathbf{3} \otimes \mathbf{3} \otimes \mathbf{3} = \mathbf{10}_S \oplus \mathbf{8}_M \oplus \mathbf{8}_M \oplus \mathbf{1}_A.$$



$$\mathbf{3} \otimes \mathbf{3} \otimes \mathbf{3} = \mathbf{1} \oplus 2 \times \mathbf{8} \oplus \mathbf{10}.$$

Since for these, by Table 15.3,  $B = \frac{1}{3} + \frac{1}{3} + \frac{1}{3} = 1$  the  $\mathbf{8}$  of this construction satisfactorily accounts for the eight-fold pattern of  $B=1$ , spin  $\frac{1}{2}$ .

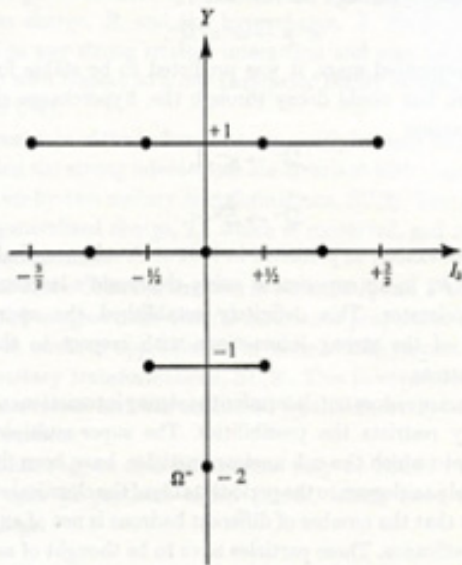
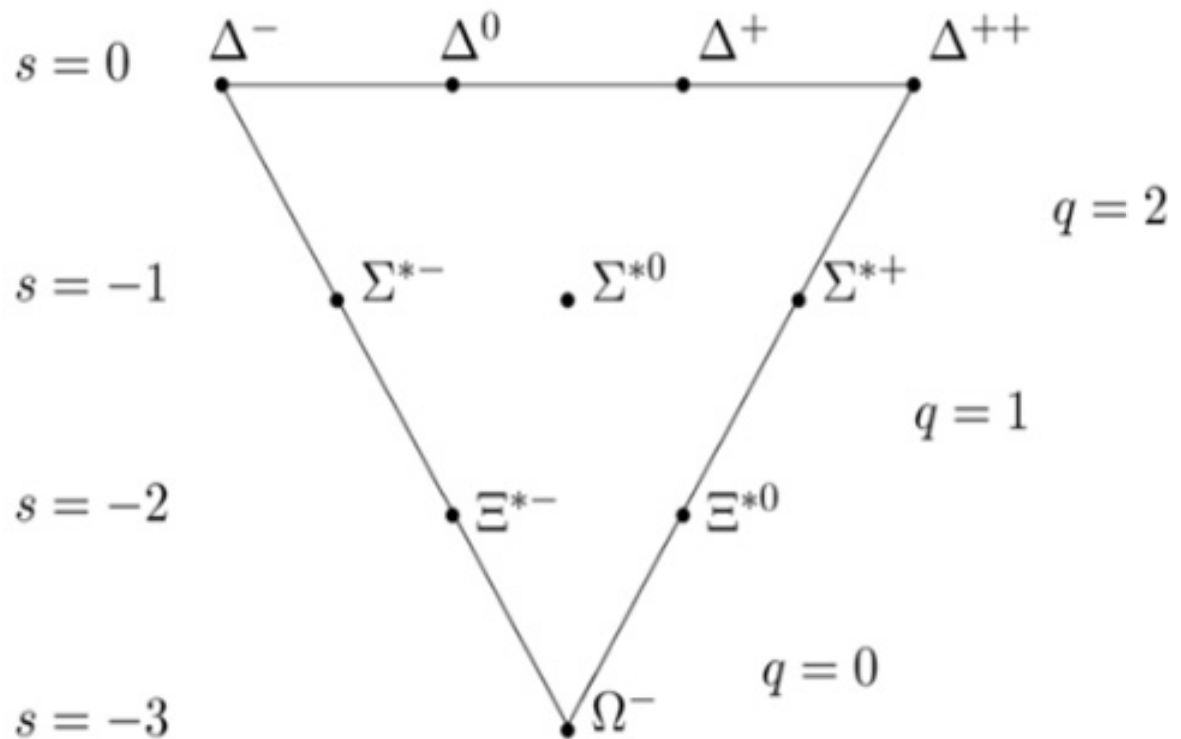
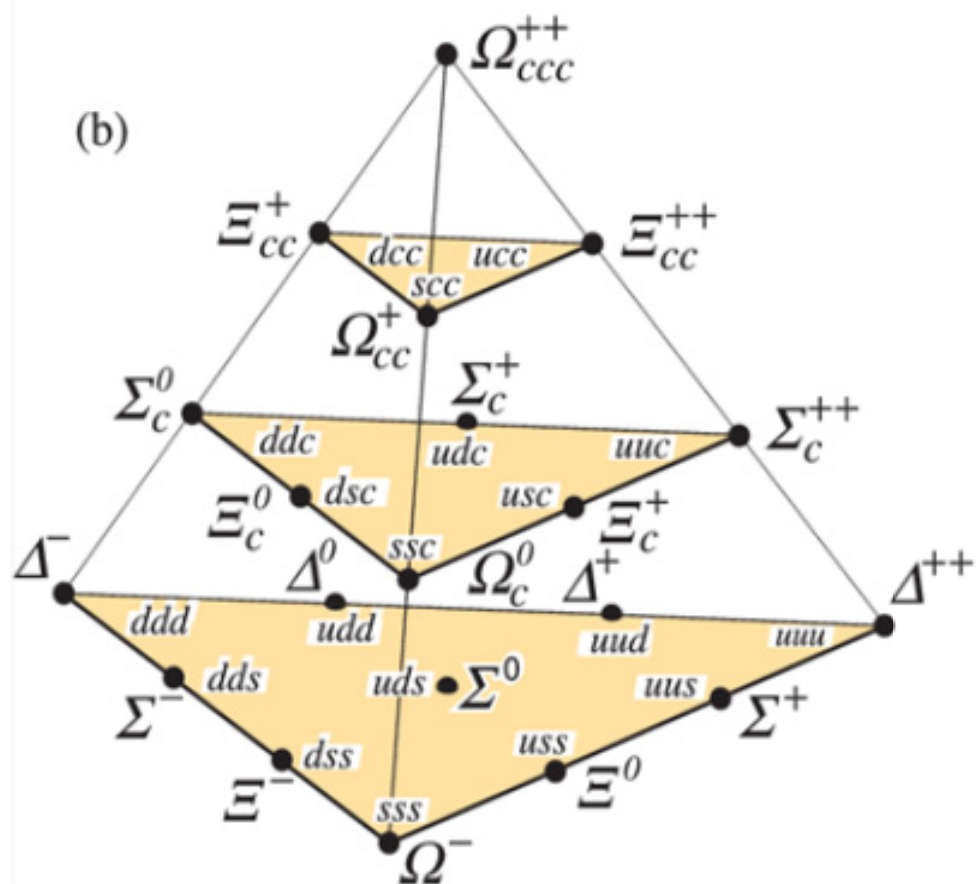
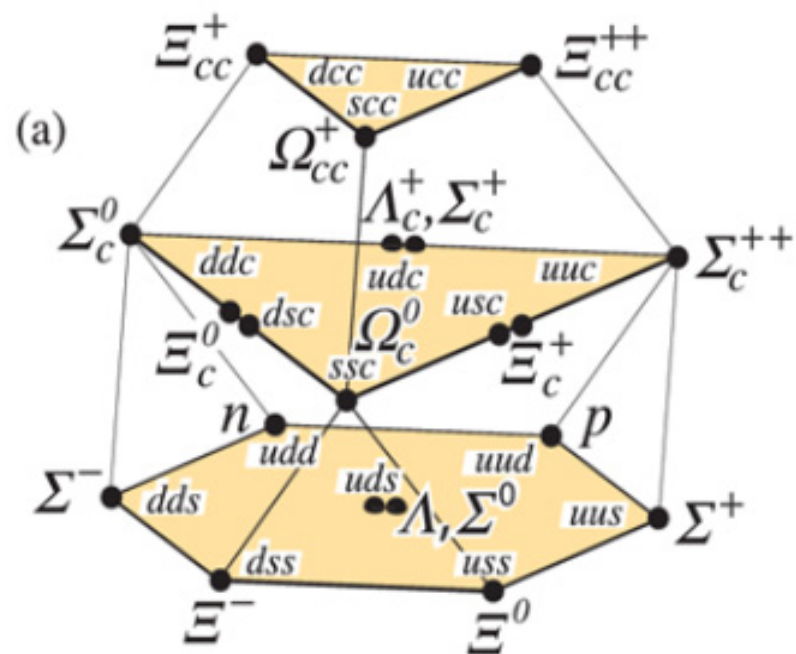
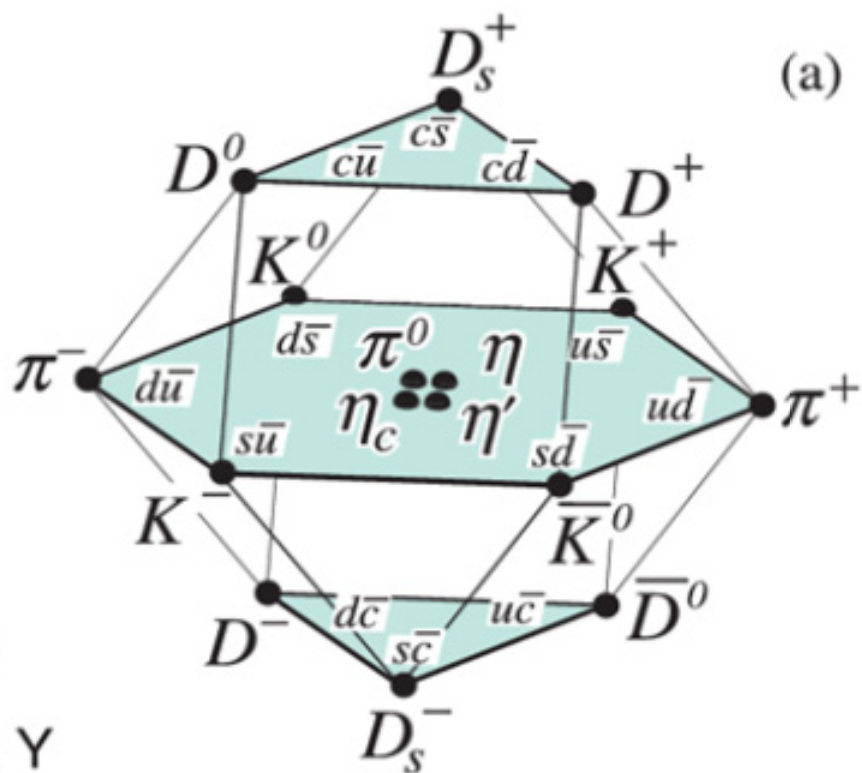


FIG. 15.6. The decuplet,  $\mathbf{10}$ , which may be formed by combining three basic quark triplets,  $\mathbf{3}$ . Nine particles corresponding to the three upper rows, with  $B=1$  and spin  $\frac{3}{2}$ , were found by 1962. The tenth particle,  $\Omega^-$ , corresponding to the lower vertex was discovered in 1964.









# ELEMENTARY PARTICLES

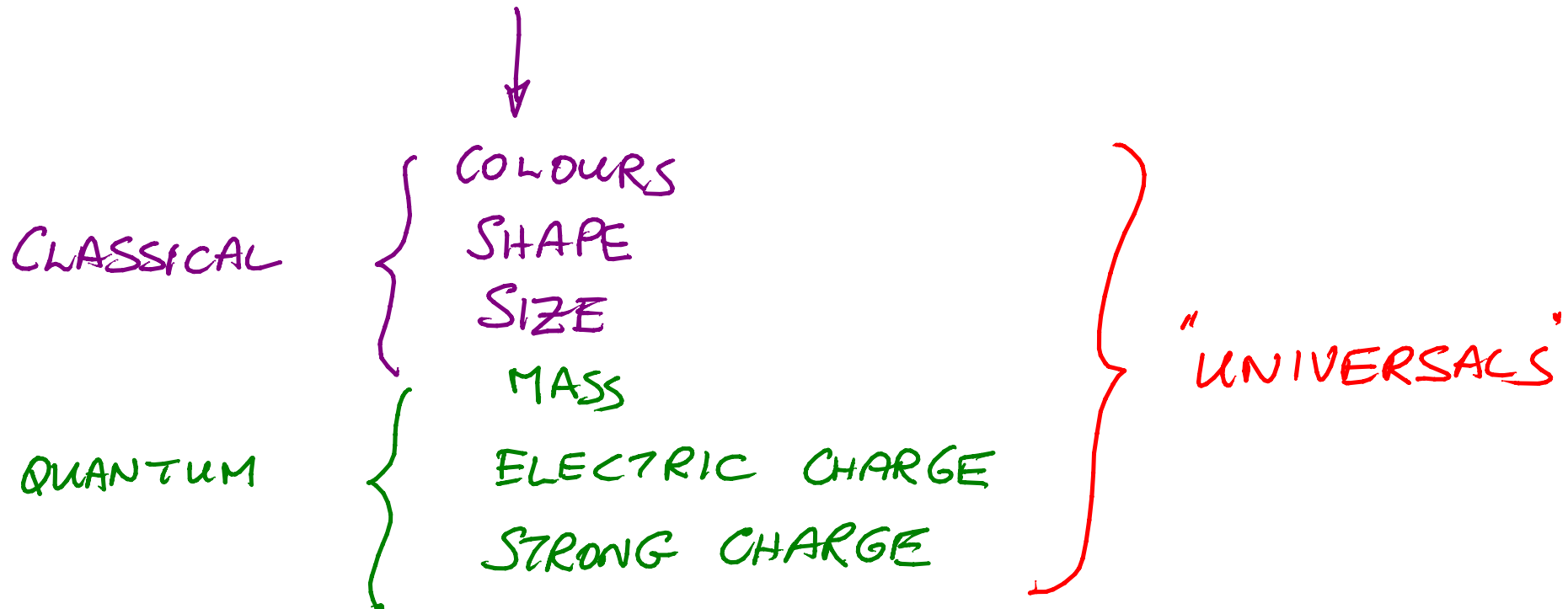


I II III  
Three Generations of Matter

# REALITY OF PROPERTIES, LAWS, CAUSES, RELATIONS

• ARE THINGS DISCUSSED IN HUMAN LANGUAGE  
& SCIENCE REAL?

• PHYSICAL THINGS ACT (INTERACT) BY VIRTUE  
OF THE PROPERTIES THEY HAVE:



CAN ASK THE QUESTION

— ARE THESE UNIVERSALS REAL ?

— OR IS IT THE OBJECTS WHICH  
HAVE THESE PROPERTIES THAT ARE REAL?

THE ANSWER IS THAT BOTH ARE

1) WE PERCEIVE OBJECTS AND KNOW THEIR  
REALITY BY VIRTUE OF THEIR PROPERTIES

FRANKLIN — WE KNOW A TABLE EXISTS

BECAUSE OF ITS COLOUR & SHAPE  
REAL

MY EXAMPLE — KNOW A NUCLEUS IS REAL  
BECAUSE OF ITS ELECTRIC  
CHARGE.

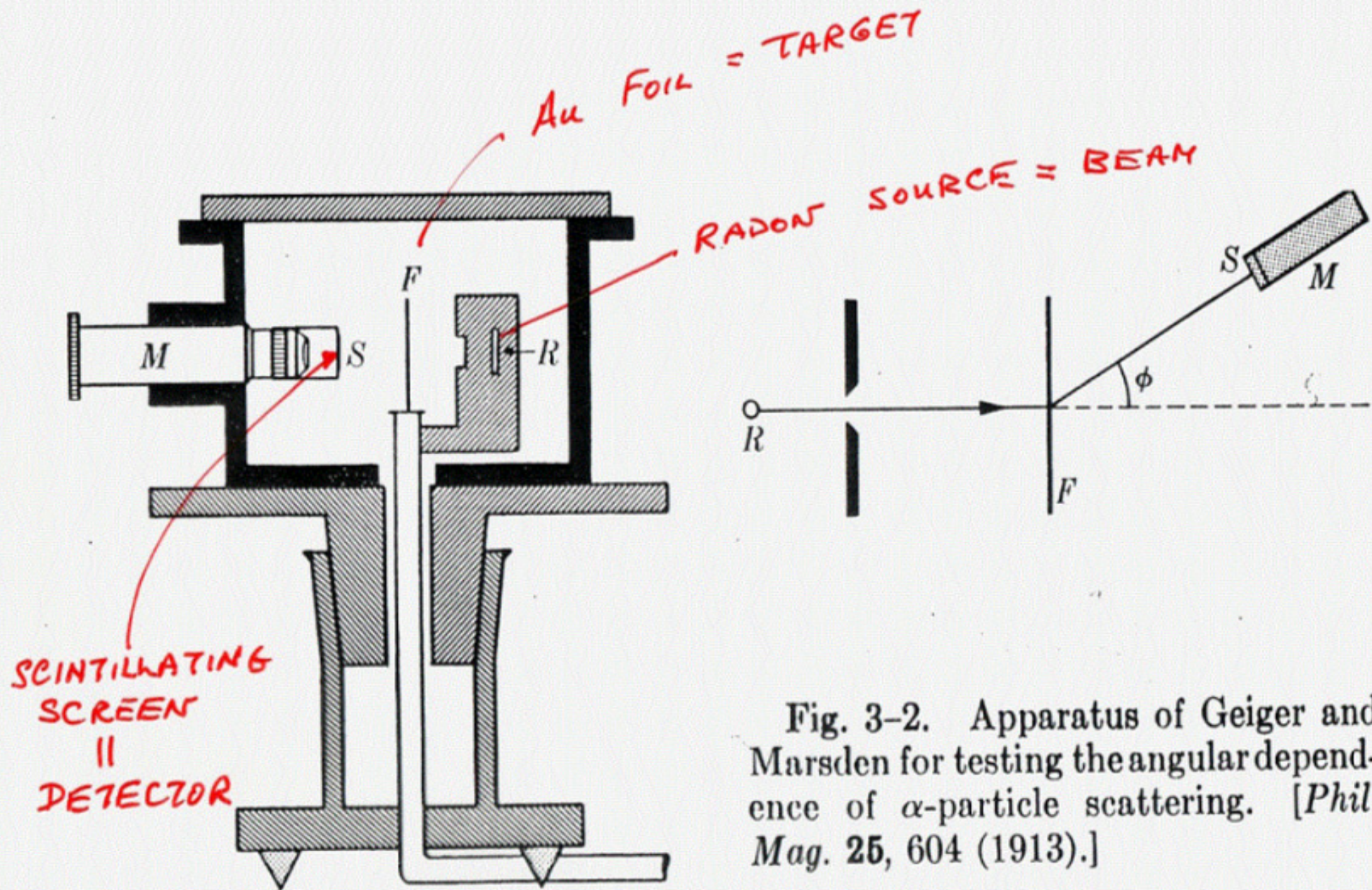


Fig. 3-2. Apparatus of Geiger and Marsden for testing the angular dependence of  $\alpha$ -particle scattering. [*Phil. Mag.* 25, 604 (1913).]

2) PHYSICAL LAWS → REALITY OF UNIVERSALS

OBJECTS HAVE PROPERTIES WHICH ALLOW THEM TO INTERACT WITH EACH OTHER

↓  
PHYSICAL LAWS

MASS → GRAVITATION

ELECTRIC CHARGE → COULOMB  
MAXWELL

QUARK COLOR → CHROMODYNAMICS

DISTANCE FROM EVERYDAY "LANGUAGE"

REAL

EXISTENCE OF PHYSICAL LAWS ARGUES FOR REALITY OF ATTRIBUTES.

# CAUSE

CAUSE IS A CRUCIAL CONCEPT IN  
PHYSICAL SCIENCE CAUSAL RELATION  
OF EVENTS IN SPACE-TIME

$$F = G \frac{m_1 m_2}{r^2}$$

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + g_{\mu\nu} \Lambda = \frac{8\pi G}{c^4} T_{\mu\nu}$$

$$i\hbar \frac{\partial \psi}{\partial t} = H \psi$$

PHYSICAL LAWS DO NOT DESCRIBE A "CAUSE"

→ WHAT "CAUSES" GRAVITY

DESCRIBES CAUSAL INTERACTIONS

"FROM THE OUTSIDE"

# SPACE - TIME

• THE OBJECTS SCIENCE DISCUSSES & THEIR INTERACTIONS ARE EMBEDDED IN SPACE-TIME. → TRIVIAL FOR MACROSCIENCES

• QUESTION →

IS SPACE JUST THE RELATION OF OBJECTS?  
OR DOES SPACE-TIME HAVE REALITY  
LIKE THE OBJECTS THEMSELVES?

KANT'S ARGUMENT → THE SPACE  
OCCUPIED BY MY RIGHT HAND IS DIFFERENT  
(INCOMMENSURABLE) WITH THAT OCCUPIED  
BY MY LEFT → A REAL THING.

IN COSMOLOGY & MICRO PHYSICS SPACE-TIME  
HAS ATTRIBUTES OF REAL THING.

— GEOMETRY OF SPACE-TIME

— EXPANSION OF SPACE-TIME

— PERMEATION OF UNIVERSE BY FIELDS

HIGGS

INFLATON

QUINTESSENCE

— QUANTUM FLUCTUATIONS

ENERGY DENSITY OF SPACE-TIME

— QUANTUM GRAVITY

THEORY  $10^{96} \text{ kg m}^{-3}$

OR

REALITY  $10^{-26} \text{ kg cm}^{-3}$



# IMPORTANT PROPERTIES OF SPACE-TIME

INVARIANCE PROPERTIES  $\rightarrow$  CONSERVATION LAWS

SPACE {  
TRANSLATION  $\rightarrow$  MOMENTUM  
ROTATION  $\rightarrow$  ANGULAR MOMENTUM  
REFLECTION  $\rightarrow$  PARITY

TIME {  
TRANSLATION  $\rightarrow$  ENERGY  
REFLECTION  
= REVERSAL  $\rightarrow$  ?

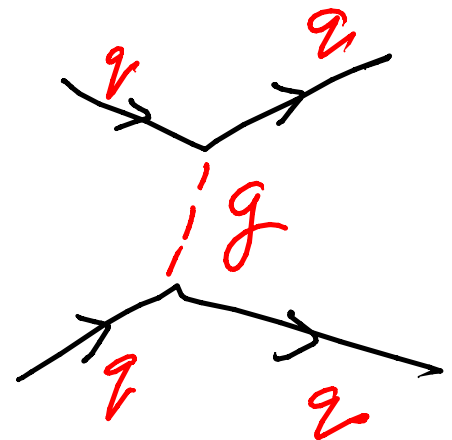
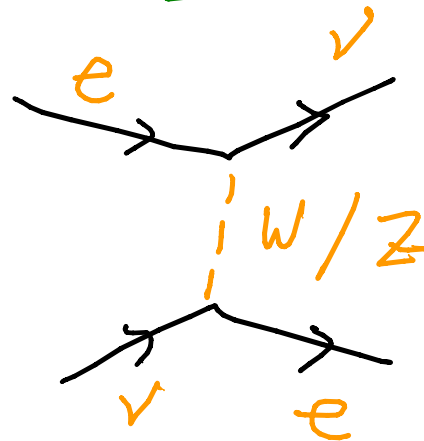
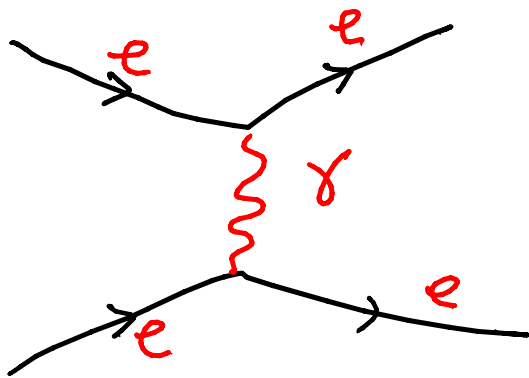
# LOCALITY

FRANKLIN REGARDS LOCALITY AS CENTRAL TO  
PHYSICAL THEORIES

TRUE — THIS IS EMBEDDED IN MODERN  
QUANTUM FIELD THEORY

FORCES ARE QUANTIZED

INTERACTIONS AT POINTS IN SPACE-TIME



# NON-LOCALITY IN QUANTUM MECHANICS

BASIC IDEAS IN QUANTUM MECHANICS

INTRODUCE **NON-LOCALITY**

THE **WAVE-FUNCTION** IS AN ESSENTIALLY  
NON-LOCAL DESCRIPTION

↳ THINK ABOUT 2-SLIT  
EXPERIMENT WITH ELECTRONS  
(SEE FEYNMAN BOOK)

EINSTEIN - PODOLSKY - ROSEN

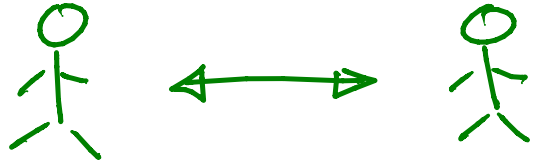
BELL INEQUALITIES

ALAIN ASPECT EXPERIMENTS

} QUANTUM  
MECHANICS  
IS A NON-LOCAL  
DESCRIPTION OF  
REALITY.

# TIME

SPACE IS EASILY DISCUSSED IN NATURAL LANGUAGE



I AM HERE. YOU ARE OVER THERE

HARD TO DESCRIBE TIME IN THIS WAY  
MOST OF SCIENCE DOES NOT HAVE TO  
HAVE A PROFOUND UNDERSTANDING OF TIME

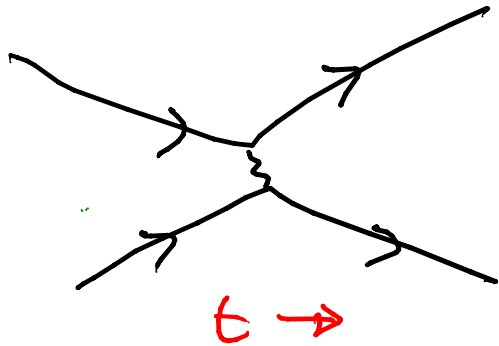
$$S = vt$$

TIME IS WHAT PASSES WHEN  
YOU MOVE AROUND

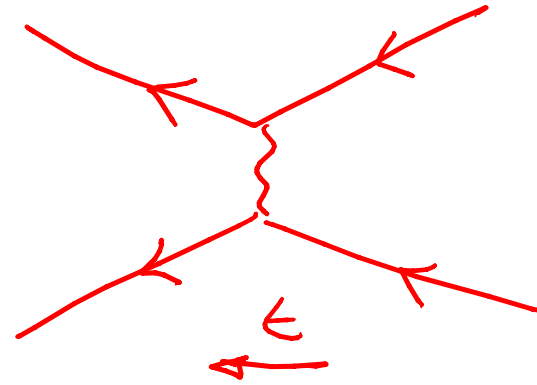
$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

TIME IS WHAT CHANGES  
WHEN THE  $\vec{B}$  FIELD  
PRODUCES AN  $\vec{E}$  FIELD

ALL PHYSICAL PROCESSES ARE  
REVERSIBLE ON THE MICROSCALE



≡



$$S = v t$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

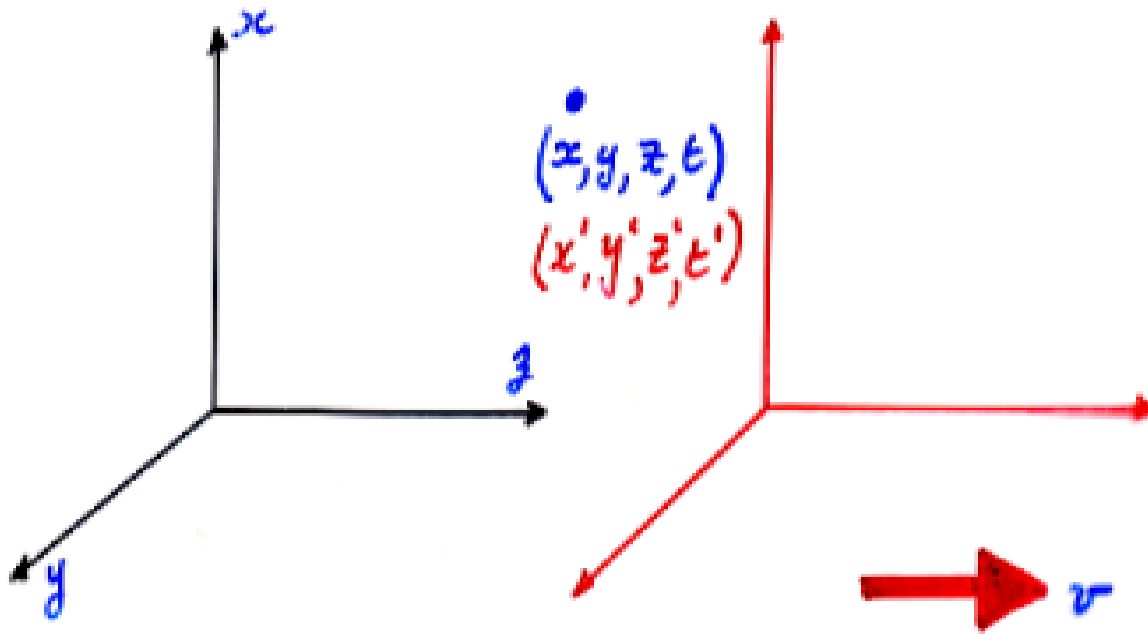
$$i\hbar \frac{\partial \psi(+)}{\partial t} = H \psi(t)$$

$$S = \frac{dx}{d(-t)} = -t$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial (-t)}$$

$$i\hbar \frac{\partial \psi(-t)}{\partial (-t)} = H \psi(-t)$$

TIME IS NOT SEPARATE FROM SPACE  
AS WE KNOW FROM SPECIAL RELATIVITY



$$x' = x \quad ; \quad y' = y$$

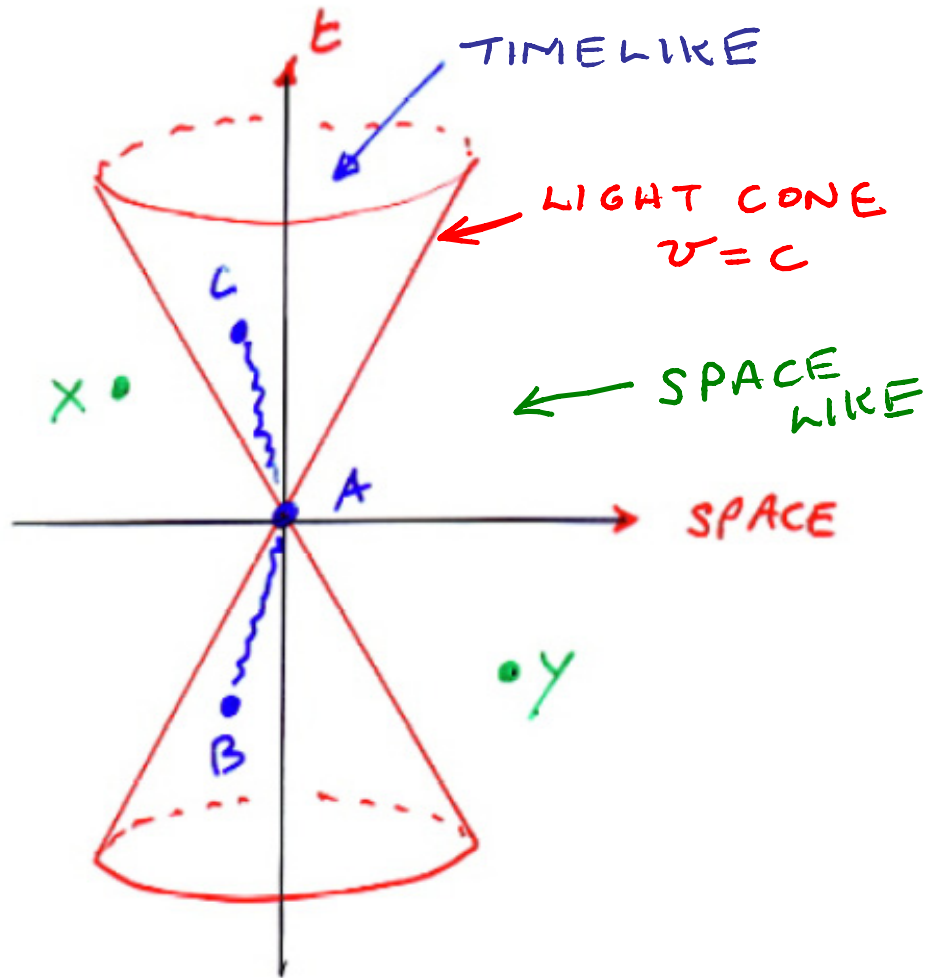
$$z' = \gamma^v (z - vt)$$

$$t' = \gamma^v \left( t - \frac{\beta}{c} \cdot z \right)$$

} note mixing  
of  
z and t.

# HOW CAN TIME FLOW WHEN DIFFERENT?

OBSERVERS CAN SEE EVENTS WITH DIFFERENT TIME ORDERING



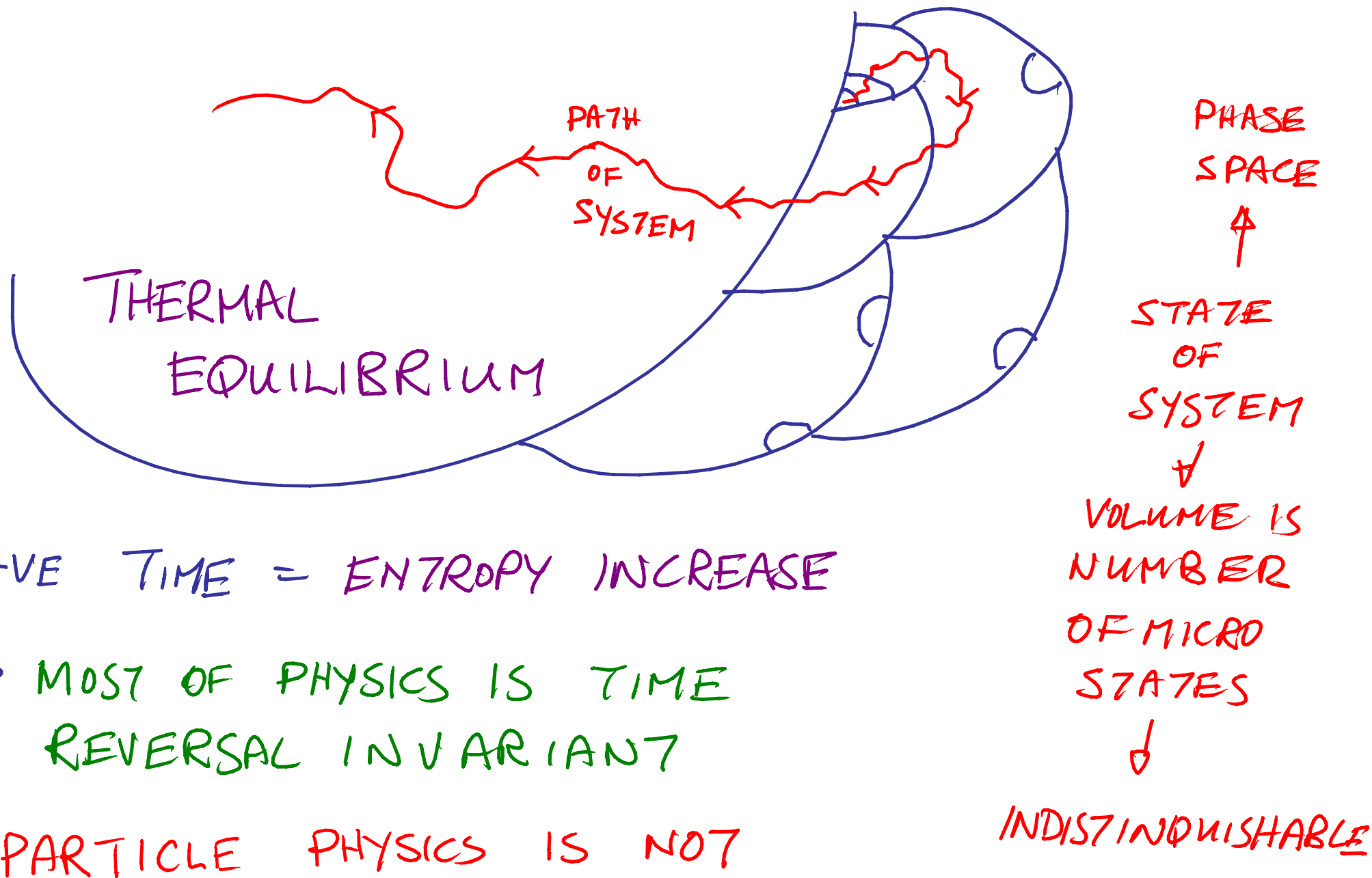
- ONLY EVENTS INSIDE THE LIGHT-CONE CAN BE CAUSALLY CONNECTED

$$B \rightarrow A \rightarrow C$$

- X, A & Y CAN HAVE NO CAUSAL CONNECTIONS WOULD REQUIRE  $v > c$

- TIME LIKE
  - SAME ORDERING OF EVENTS FOR ALL OBSERVERS
- SPACE LIKE
  - TIME ORDERING CAN BE REVERSED FOR DIFFERENT OBSERVERS

# DIRECTION OF TIME



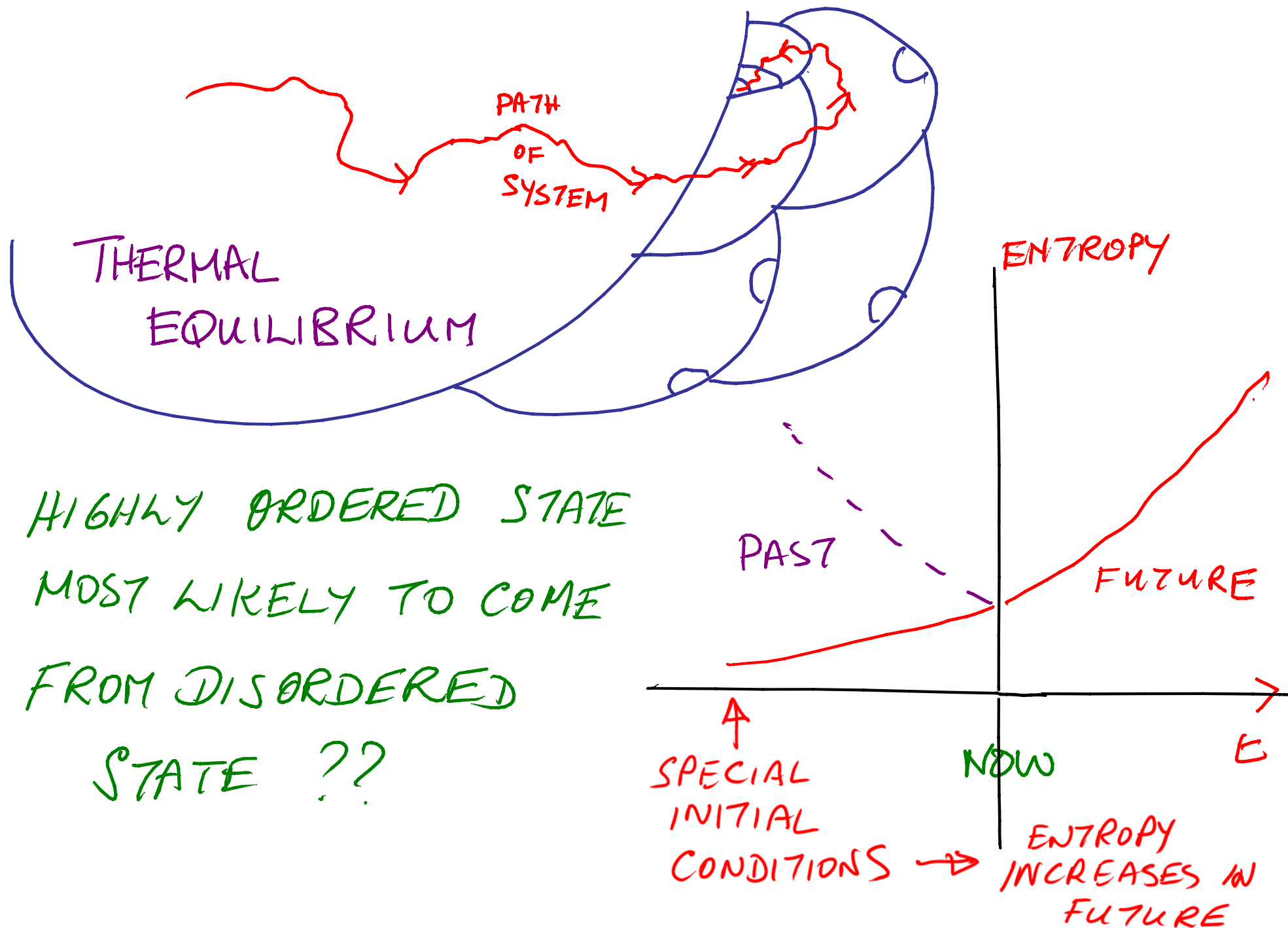
+VE TIME = ENTROPY INCREASE

- MOST OF PHYSICS IS TIME REVERSAL INVARIANT

PARTICLE PHYSICS IS NOT



ARGUMENT SEEMS TO WORK IN REVERSE



# ENTROPY & THE BIG BANG

- WHERE DID INITIAL LOW ENTROPY COME FROM? → GRAVITY FORMING STRUCTURES?
- PRIMORDIAL FIREBALL THERMAL EQUILIBRIUM
- WOULD EXPECT INITIAL STATE — MINIMUM ENTROPY
- THERMAL EQUILIBRIUM — MAXIMUM ENTROPY
- PERMITTED AMOUNT OF ENTROPY INCREASES AS THE UNIVERSE EXPANDS
- IS DIRECTION OF TIME DEFINED BY EXPANSION OF UNIVERSE?

EMPEROR'S NEW MIND  
ROGER PENROSE

# PHYSICAL SCIENCE

→ BUILDS ON NATURAL LANGUAGE

→ EXTENDS SCOPE OF TRADITIONAL LANGUAGE

- SPACE / TIME

→ DEVELOPS NEW UNIVERSALS

STRONG FORCE

COLOUR CHARGE

STRANGENESS







