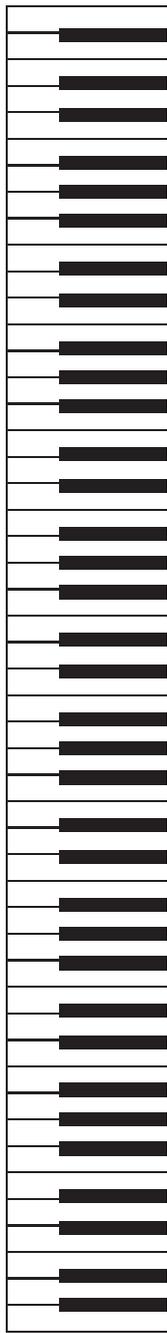
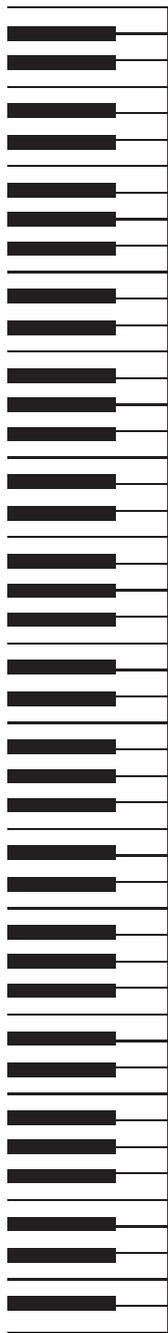


Object size in metres	log	OBJECT	log	Energy in electron Volts		
AUDIBLE HI	Ym	24	Coma cluster	-30	weV	AUDIBLE LO
	Zm	21	Milky Way galaxy	-27	xeV	
	Em	18	Globular cluster	-24	yeV	
HARMONICS	Pm	15	Black Hole in MW	-21	zeV	
	Tm	12	Orbit of Saturn	-18	aeV	
	Gm	9	Star like the Sun	-15	feV	
	Mm	6	Asteroid Ceres	-12	peV	
	km	3	Hill	-9	neV	
	m	0	Tree	-6	$\mu$ eV	
	mm	-3	Fly	-3	meV	
	$\mu$ m	-6	Cell	0	eV	
	nm	-9	DNA base pair	3	keV	
	pm	-12	Fm <sup>99+</sup> Atom	6	MeV	
	fm	-15	Proton or Neutron	9	GeV	
	am	-18	Probed by Large	12	TeV	
	zm	-21	Hadron Collider	15	PeV	
	ym	-24	Energy scale gap	18	EeV	
	xm	-27	Unification of	21	ZeV	
	wm	-30	interactions?	24	YeV	HARMONICS
	vm	-33	Early universe	27	XeV	
AUDIBLE LO	PLANCK LIMIT FOR LENGTH AND ENERGY					AUDIBLE HI



## MUSIC OF THE SPHERES

The sizes of objects in the universe vary enormously from the femtometre (fm) diameter of a proton to the zettametres (Zm) span of a typical galaxy. One way to gain a sense of the various units of length used here is to successively step up by a factor of a million. The width of a molecule like DNA, for example, is approximately a million femtometres, the nanometre (nm) of nano-technology. In turn, a million nanometres would equal a millimetre (mm), the size of a small insect.

A million millimetres would correspond to the familiar kilometre (km) extent of, say, a hill in a landscape while a million kilometres is called a gigametres (Gm), the size of a typical star like the Sun. A million such gigametres, denoted a petametres (Pm), is about the radius of the Black Hole at the centre of our Milky Way galaxy, in turn, is around a million times larger with a diameter of a million petametres, namely a zettametres (Zm).

The Large Hadron Collider (LHC) near Geneva and future accelerators plan to probe distance scales of one millionth of that of the femtometre sized proton, namely one zeptometre (zm), in order to study sizes approaching those where the fundamental forces are expected to be unified. The seven steps of a factor of a million from the zeptometre unification scale to the zettametres span of a galaxy may be represented by the seven octaves of a typical piano keyboard.

<http://www.maths.tcd.ie/~nhb/xmpl/spin.pdf>

In the figure, the keyboard to the right illustrates the correspondence. Each whole tone of two semitones would relate to a factor of ten increase in size. A succession of six whole tones or twelve semitones would correspond to a million fold increase, precisely an octave. Each object listed is about a thousand times the size of the one below, the difference being related to six semitones.

The energy scale on the right increases with the pitch of the notes. Energy is measured in units of electron Volts (eV). Particles of megavolt (MeV) energies are required to probe structures of picometres (pm) atomic sizes while the teravolt (TeV) energies of the LHC and the Tevatron near Chicago are needed to examine the attometres (am) scales of quarks and gluons.

The lowest note of the piano on the right, being produced by the longest pianoforte string, relates to the largest galaxies. In fact, the deeper lowest audible note, over half an octave lower, corresponds to the size of the observable universe. For the piano on the left in the figure, the pitch increases with size.

At the other end of the scale, the highest note of the piano on the right reaches the point at which forces are expected to unify. The highest audible note, some two and a half octaves higher up, signifies the point at which quantum and gravitational theories have reached their limit, the Planck length beyond which our current understanding of the natural world is notably incomplete.