Title
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Permalink
https://escholarship.org/uc/item/64w3s2cf

Journal
Astronomische Nachrichten, 330(7)

ISSN
0004-6337

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Publication Date
2009-08-01

DOI
10.1002/asna.200911227

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Peer reviewed
Multiverses of the past

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Received 2009 Mar 13, accepted 2009 May 5
Published online 2009 Jul 20

Key words  history and philosophy of astronomy

More than 2000 years ago, Epicurus taught that there are an infinite number of other worlds, both like and unlike ours, and Aristotle taught that there are none. Neither hypothesis can currently be falsified, and some versions of current multiverses perhaps never can be, which has contributed to occasional claims that “this isn’t science!” (a common complaint about cosmology for centuries). Define “cosmos”, or “world”, or “universe” to mean the largest structure of which you and the majority of knowledgeable contemporaries will admit to being a part. This begins with the small, earth-centered worlds of ancient Egyptian paintings, Greek mythology, and Genesis, which a god could circumnavigate in a day and humans in a generation. These tend to expand and become helio- rather than geo-centric (not quite monotonically in time) and are succeeded by various assemblages of sun-like stars with planets of their own. Finite vs. infinite assemblages are debated and then the issue of whether the Milky Way is unique (so that “island universes” made sense, even if you were against the idea) for a couple of centuries. Today one thinks as a rule of the entire 4-dimensional space-time we might in principle communicate with and all its contents. Beyond are the modern multi-verses, sequential (cyclic or oscillating), hierarchical, or non-communicating entities in more than four dimensions. Each of these has older analogues, and, in every milieu where the ideas have been discussed, there have been firm supporters and firm opponents, some of whose ideas are explored here. Because astronomical observations have firmly settled some earlier disputes in favor of very many galaxies and very many stars with planets, “other worlds” can now refer only to other planets like Earth or to other universes. The focus is on the latter.

1 Introduction

A couple of generations ago, most introductory science texts began by telling you what the ancient Greeks had thought about the subject. Many astronomy books still do. In the case of world views, we can actually go back a bit further, because the Egyptians and Babylonians left both images and texts describing their very compact and short-lived worlds; and there are texts indicating that some early inhabitants of India had in mind larger and very long-lived worlds, perhaps cyclic. All to varying extent associate gods and goddesses with origins and with important structures – the Earth, ocean, sky, air, Sun, Moon, Venus, and some constellations. The Babylonian ones are more easily identified with actual star patterns than the Egyptian, and some of their patterns and names have come down to us through the Greeks.

In none of these is there any obvious indication of worlds before, after, or spatially outside the familiar one. Also general are small size for the earth, the sky as a hemispherical cap atop it, and a time since creation of at most a few hundred generations, which may even have been recorded. A number of non-Western creation myths have similar traits. Some do not (the Australian “dream time”, for instance). The cosmos of Genesis is largely the Babylonian, but with only one higher authority.

In contrast, the Greeks whom we think of as philosophers entertained an enormous range of possible images of the cosmos, finite or infinite, sun- or earth-centered, and single, multiple, or even infinite in number. Thus the multiverse concept has a Greek name, aperio kosmoi, multitude or plenitude of worlds or forms, remembering that cosmos and cosmetics share a root. One can also find within the multiple Greek traditions some hint at least of the three conceivable sorts of multiple worlds, (a) following one another sequentially in time, (b) hierarchically arranged in a single space, or (c) in separate or at least separated non-communicating spaces. That other worlds might have different numbers of dimensions is probably not a Greek idea, but can be found as far back as Immanuel Kant in 1749. Current multiverses are generally of type (c), though a few (a)’s and (b)’s lingered into the 20th century.

The literature addressing history of cosmology is extensive, including first, second, and third hand sources, with multiple worlds generally scattered, raisin-like, among other more doughty topics (though Gale 1990 is focused largely on early multiverses). The sources from whom I have borrowed most extensively include Kragh (1996, 2007), Harrison (1985, 1987, 2000), Danielson (2000), Dick

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(1982, 1998), Hoskin (1997), Hockey et al. (2007), and Crowe (1994), with some specific items cherry-picked from Cantor (2001), Barrow Tipler (1986), and Tolman (1934a), as well as additional sources cited below.

At least four sorts of caveats and cautions are necessary, in addition to the overall one that we cannot, or cannot without enormous effort, put ourselves back into the mindset of our predecessors, whose priorities, goals, assumptions, and all were very different from ours. Just keep in mind that they were, on average, as smart and as hard working as we are, though the extremes may have changed, just because we select our colleagues from a much larger pool than Aristotle could.

First caveat: have philosophers, scientists, and all ever been completely free to think, say, write, and teach whatever they want? No, nor are we truly now. None of us is currently at risk of Socrates’ hemlock or Bruno’s fire (and, standing in line at hub airports, we may even occasionally envy Galileo his house arrest — it was a very nice house), but our colleagues of the 21st century still risk their grants, students, tenure, and places at the conference dinner table if they stray too far from the beaten paths (Lopez Corredoira Castro Perelman 2008). Present acceptable paths include some lined with strings, others with primroses, but none with non-cosmological redshifts. Thus one might try to ask whether our predecessors really meant what they wrote: the probably apocryphal “eppur se muove” of Galileo reflects this.

Next it is important to remember that people and peoples do change their minds. In some tomb paintings, Ra rides his day and night boat outside Nut’s body of stars, in some inside. Herschel’s personal cosmos evolved over his 40-year involvement in astronomy, and Harlow Shapley provides an almost-modern example of someone who thought he was “wiser today than he was yesterday”. Early in his career, he supposed with nearly everyone else that the Milky Way was less than 10 kpc across, and he supported existence of other galaxies as well. But his own work at Mt. Wilson Observatory on pulsating variable stars in globular clusters (RR Lyraes and Type II Cepheids, we would now say) persuaded him by 1920 that we were nearly 20 kpc from the center of a 100 kpc galaxy, and that everything observed up to his time was inside it.

Words and drawings can disagree. Thomas Digges, Giordano Bruno, and William Gilbert, all around 1600, wrote that the universe was infinite, stars were suns, and other planetary systems like ours. Yet their drawings all have a solar system occupying more than half the page and much smaller stars studded around the outside. Two factors enter, I think. First, they necessarily showed more details where more was known. Time was, our own introductory astronomy books took more than half the pages to get out of the solar system. Second, pieces of paper were invariably finite in size, and, indeed, more expensive than we of the solar system. Second, pieces of paper were invariably finite in size, and, indeed, more expensive than we.

A last and perhaps most important caveat: Assuming for the moment that the goal of science so far has been to arrive at our current views, you still must not expect anything like monotonic progress, even if we let our toes touch only on the peaks of genius. The spherical earth of the Pythagoreans was followed by the prolate one of Democritus, who, however, surrounded it with a thick shell of stars, rather than a single crystalline sphere. An infinite chaotic region was outside the thick shell. Aristotle is back to spherical symmetry but finite size. Prolatism returns with Hildegard of Bingham (12th century), whose world resembles a lumpy flower, with the sun and outer planets more distant than the fixed stars, clouds nearby, but hail and lightning between the stars and the lucidus ignis, while at least a subset of the Greeks had the sequence of distances of the seven wanderers right, based on their orbit times around the sky. Dante’s nine spheres (c. 1310–1314) are in some sense her successor.

Copernicus, of course, counts as one of the mountain tops (but he puts all the stars in a thin layer). Martin Luther’s 1534 Biblia is earth-centered, and he has some difficulty in placing “the waters above” in among the stars around a spherical Earth. His clouds, Sun, and stars are more or less coextensive. The infinite worlds of Digges, Bruno, and Gilbert count as another peak, both because they allow the realm of the stars to extent infinitely (though Digges at least requires that there also be space for angels and the elect in that endless region) and because they seem to have meant what they said to be taken seriously, in contrast to a century or two of church-based writers who opined that an omnipotent creator could have made an infinite number of worlds, but chose not to. Leibniz said roughly the same as late as the 17th century.

Kepler has to be taking us forward, right? And his Epitome of Copernican Astronomy indeed considers the possibility of the sun being an ordinary star in an infinite universe. But he backs firmly off, not just from infinity, but even from “stars are suns” and distant, on the basis of a sort of Olbers Paradox argument (not, of course, a paradox and not due to Olbers). His last word on the subject avers: “Hence it is quite clear that the body of our sun is brighter beyond measure than all the fixed stars together, and therefore this world of ours does not belong to an undifferentiated swarm of countless others.” But he favors inhabitants on the moon and on Jupiter (for whose seeing the Galilean satellites were created, since Jovians will find Mercury, Venus, Earth, and Mars very difficult to resolve from solar glare). And he is not averse to humans eventually visiting these places. Kepler himself remarked upon his poor eyesight (to which Sirius looked as big nearly as a full moon), and his Olbersish worry might well have been assuaged by the realization that the angular diameters of stars are VERY small! Very recently someone has blamed Galileo’s fading sight for his describing the rings of Saturn as ansae or handles.
Have you ever looked at Saturn through a truly Galilean telescope?

If your interest in the past is already stretched to its maximum, please skip the next five sections (which trace different sorts of aperio kosmos from the Greeks almost to the present) and go straight to the last two sections on solved and unsolved problems.

2 The Greeks had a word for it

Well, at any rate, we have words associated with their names that don’t always quite convey their attitudes toward plentitude of worlds! Epicurean (good food), Platonic (unconsummated affection), Socratic (inefficient teaching method), Stoic (excessively brave), Aristotelian (starkly, formally logical and probably wrong), and perhaps others.

So let us look for a moment at their assorted kosmoi. A standard over-simplification recognizes three basic types, Aristotelian, Epicurean, and Stoic. Aristotle (384–322 BCE) comes first, not chronologically, but in long-term significance, because it was his model, folded into medieval church doctrine, that became compulsory in the Christian west for a good many centuries. The Aristotelian (and the Platonic before him) universe was earth-centered, infinite in both past and future duration, but finite in size and unique. He accepted the 400 000 stades (about 40 000 km) size for the Earth, which must, therefore, predate Eratosthenes (c. 275–195 BCE), who generally gets credit for it in introductory astronomy books.

The Epicurean universe begins with Anaxagoras (6th cent. BCE) and Leucippus (5th cent. BCE) and atoms moving in an infinite void, world forming, dissolving, and reforming. Epicurus himself (341–270 BCE) comes in the middle. And the most poetic description of worlds coming and going was that of the first century CE Roman poet, Lucrètius, a quote from whom long adorned the seminar room wall in what had initially been Fred Hoyle’s Institute of Theoretical Astronomy in Cambridge. Finite worlds in an infinite space-time roughly says what the Epicurean and steady state universes had in common.

And these have smaller still to bite ’em

Third, and perhaps combining all the disadvantages of the other two, was the cosmos of the Stoic school (founded by Zeno of the paradox c. 344–262 BCE) with a finite sphere of stars surrounding the solar system, and an infinite void beyond. Compress the stellar sphere to a spheroid and allow the solar system to move a bit off center, and you have something like the (unique) galaxy of William Herschel, Jacobus Kapteyn, and most astronomers temporally in between.

The idea persisted into the 20th century, Alfred North Whitehead (Prince 1954) subscribing to a hierarchical multi-
tiverse “like a Chinese toy with a nest of boxes, one within
the other.” I think one now has to say that quantum me-
chanical considerations exclude multiple worlds on scales
smaller than our own, while larger ones are not so easy to
rule out (especially if you are pro-fractal). Admit-
tedly some, like that put forward by G.F.R. Ellis (in Carr
2007), belong to types I do not claim to understand.

You don’t often see images that might correspond to
more than one spatial level of universe, but William Cun-
ingham’s The Cosmographical Glass (1554) has a woodcut
of a realistic (sweating and straining) Atlas holding up our
world and its surroundings (complete with armillary sphere
and primum mobile), and he is kneeling, obviously much
burdened, in what looks like an ordinary country scene with
a town in the background, seemingly part of some enor-
mously larger world. The author may not have meant it that
way!

A fractal system differs from a hierarchical multiverse
in that all units at a given level of organization are about
the same size. The next level is made of larger things, but
much further separated, so that average density declines as
you go from one to the next. Something of the sort was
advocated by Emanuel Swedenborg (1688–1772), Thomas
Wright (1711–1786, nearly always said to be “of Durham”,
presumably because he was born and died near there and de-
clined a formal position at St. Petersburg), and Johann Lam-
bert (1728–1777), for whom the largest firmly established
units were galaxies (but Lambert’s stars all had planets, and
his celestial bodies had life).

Fractal went out of fashion with the 19th century de-
cline of Island Universes, but was revived by Carl Charler
(1862–1934) early in the 20th century. He had in mind solv-
ing Olbers’s paradox and the gravitational equivalent of von
Seeliger as well as accounting for the appearance of a sky
plot of the NGC nebulae in which the Virgo and Coma clus-
ters are very conspicuous and seem to have other structures
associated with them.

When existence and then clustering of galaxies became
the majority view, fractals could survive only at the level
of superclusters and beyond. Gerard de Vaucouleurs (1918–
1995) insisted to the end that there must be larger structures,
hierarchically arranged, on the grounds that it would be re-
markable if, after a couple of millennia of “expanding hori-
zons”, our own lifetime should witness the discovery of the
largest structures and of the correct distance scale. Remark-
able, perhaps, but, it seems, true. Later attempts at defend-
ing the fractal version of multiple worlds have foundered
on the continuity in density vs. scale observed from galaxy
surveys of the 1980’s, to X-ray clusters, to SDSS structures,
and the CMB.

Whether a fractal universe is physically possible would
seem to depend on whether there is enough time for the
larger structures to recognize their boundedness and start
dynamical evolution. A possible universe, I think, but not
ours, as might have been asserted long ago when the first
radio surveys showed no clustering (Holden 1966; Payne
1967).

4 Types of multiverse: II. Oscillating or in
temporal succession

Some of the Greeks we have already met considered a recur-
ring wheel of time or oscillation between alternatingly un-
balanced forces, but the concept had its heyday in the mid-
dle of the 19th century, when scientists were struggling to
come to terms with the radiation laws and thermodynamics,
fearing a “heat death”, before cosmic expansion was found.
Some examples include Friedrich Nietzsche (1844–1890),
for whom recurrence through infinite time was the only logi-
cally acceptable cosmogony. Poincaré’s (1854–1912) recur-
rence time was a more quantitative version. Croll (1821–
1890), Ritter (1826–1908) and others invoked collisions to
keep stars going. We might draw a comparison with a 1970
attempt to merge two black holes of mass $M$ to yield an-
other also of mass $M$ plus a burst of gravitational radiation.
This doesn’t work – the product BH is always more massive
than the input ones, so the process cannot continue. Nor
does the stellar-collision version work! In the same time
frame, Rankine (1820–1872), Arhenius (1859–1929), and
Crookes (1821–1890) thought in terms of radiation flow-
ning far out into space, reforming particles, and falling back
into the galaxy to form new stars. The last 20th century ver-
tion of this was the FIB cosmology of Jeno and Madelaine
Forro Barnothy (for whom cosmic rays were photons that
had been around the universe already once). It would be un-
kind to note that Crookes probably didn’t understand his
radiometer either.

Following the advent of general relativity and an ex-
panding universe, the threat became a “cold death” rather
than a hot one, and the next version of the temporal mul-
tiverse was alternating expansion and contraction phases
(Friedman 1922, 1924; Lemaitre 1933). Tolman (1934) con-
templated two versions, one with arbitrarily small minimum
radii and one that bounced back and forth between large and
small, but non-infinitiesimal, size (aided by a cosmological
constant). Tolman understood that each cycle would have a
longer duration and reach larger radius as the quantity of
radiation increased. Thus the process could produce many
universes, but not an infinite number.

The singularity theorems of the 1970s rule out oscillations
that go down inside horizons and trapped surfaces, un-
less the universe includes material of negative energy den-
sity, not just negative pressure (like dark energy), but there
are discussions of sequential, more or less general relativis-
tic multiverses of various sorts from Bonner (1954), Dicke
& Peebles (1975), Landsberg & Park (1979) and M.A.
Markov in 1983. All are better known for other work. This is
emphatically so for John Wheeler, who, as Misner, Thorne
& Wheeler (1973) went to press, was investigating a con-
nection between geometry and pregeometry which might
somehow permit recurrent universes. The illustration shows
a hopper of brass rings being assembled (when a crank is turned) into chain mail.

Coming down almost to the present, we find the quasi-steady-state theory of Hoyle, Narlikar & Burbidge (2000), in which long-term \((10^{11} \text{ yr})\) oscillations host a number of “little bangs”, of which we are one. And, returning to main stream high energy particle physics (which changes beyond recognition every few years), we find the brane worlds (Carr 2007), in which two higher-dimension surfaces bounce off each other, heating the 4-d regime between. We are then the product of one of these collisions, which are expected to recur many times, if not an infinite number. Because the branes and their collisions reside in higher-dimensional space, brane worlds belong both to this sequential class and to the next, acausal separation, class.

5 Types of multiverse: III. Acausal separation

This is the sort that is in greater favor today than at most times in the past (though we won’t quite get to more than 4-d space until Type IV). The medieval considerations are tucked in here since they must go somewhere, and one of the prominent ideas sounds very curious to modern ears.

There are, of course, some Greeks who can be invoked in connection with, at least, very widely separated worlds, Anaximenes, Anaximander (a follower of Thales, for whom separation was a primary process), and Parmenides, around 480 BCE, who may have said that many worlds were logically necessary. His model perhaps had alternating bands of fire and darkness. If there were adjectives like Anaximenic and Parmenidian, their meanings have not come down to us, though Parmenides’ school was the Eleatic, for his home town.

The thread of astronomical knowledge and even astronomical speculation ran very thin indeed after Ptolemy (circa 100–175 CE; please think of putting those little c’s in front of many of the ancient and medieval dates). Pliny the Elder (1st century CE) had even lost the epicycles, though he concluded that “the Holy Spirit did not desire that men should learn things that are useful to no one for salvation.” Tertullian (3rd century) was even more negative in translation, wanting “no curious disputation after possessing Christ Jesus, no after enjoying the gospel!” Though in due course an inquisition was what his successors were to get. There was even a 4th to 6th century revival of flat Earth models, with the Earth at the despised bottom rather than the center of the universe. The chief proponent, Lacantius, was, according to Copernicus, a poor mathematician. Some slight recovery can be traced from the 5th century with Macrobius (whose Milky Way was made of stars according to a late, but pre-Galilean painting of his dream), Philoponus (6th century) who attempted an early synthesis of Aristotle with church doctrine, and (probably known to you for other reasons), the Venerable Bede (7th century), whose De Natura Rerum restored the Earth to sphericity and the Sun to the largest size in the solar system. An anonymous 9th century commentator even suggested that Mercury and Venus orbited the Sun, which, in turn, orbited Earth, as per Heraclides of Pontus among the Greeks, and Tycho much later.

Then, as an increasing range of Greek writings was recaptured by translations, often back from Arabic, into Latin beginning around 1150, speculation cautiously took off again, though heavily cordoned by theology. Thomas Aquinas (1223–1274) was the most influential of the welders of Aristotle to church doctrine in a way that permitted those applications of astrology that did not oppose free will. Some of his ideas were condemned in Paris in 1277 (and at Canterbury soon after), as part of a list of 219 articles, including number 34, that it was heresy to claim that the creator could not have made several worlds. Aquinas’s was a single world, and this became (with the rest of his synthesis) official doctrine in 1278.

The names associated with serious consideration of multiple worlds include William of Ockam (1280–1349, remember the little c’s), whom you know for his razor; Thomas Bradwarden (1290–1349) who had contemplated an infinite universe while a student at Oxford, but kept his ideas fairly quiet and succumbed to plague soon after being selected archbishop of Canterbury. John Buridan (1300–1360), known for the hypothetical ass which, unable to make up its mind, starved to death between two equally attractive piles of hay; and his student Nicole Oresme (1320–1382). Oresme wrote at length refuting Aristotle’s arguments against a rotating earth and in favor of the possibility of multiple worlds, sequential, hierarchical, or “entirely outside”, a la Anaxagoras.

But, concluded Oresme, though an omnipotent creator could have produced a rotating earth and many other worlds, he chose not to, leaving our stationary sphere at the center of the only cosmos. Buridan had similarly concluded that the infinite space was possible, but not the choice that G.d had made. This point of view has a very strange sound to those of us raised on particle physics, wherein “anything that isn’t forbidden is compulsory.” That mind set finally straggled to an end with Leibniz (1646–1716), who supposed that an infinite number of logically possible other worlds existed in

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1 Augustine is the hero of the tale, “What was G.d doing before he created Heaven and Earth? He was creating Hell for people who ask questions like that.” You are not supposed to think this actually happened.

2 Do you think the editor will let me get away with mentioning that . . . it was not rounded and pink, as you probably think. It was grey, had long ears, and ate grass.
the mind of G.d, but that he had chosen to create only the best. One shudders to think what some of the others might have been like. Infinite space was also for Leibniz part of the road not taken.

Meanwhile, as it were, Nicolas of Cusa (Cusanus, Krebs, and other variants 1401–1464), progressing through church hierarchy (mostly in France and Germany) stuck his metaphorical neck out and said that infinite space and an infinite number of worlds were reality. Then comes Copernicus (1473–1543), who is not really part of this story, but a second generation of Copernicans wrote about (though they could not draw on finite paper) multiple worlds (systems of planets orbiting other stars, at this stage) in infinite space. Among the best known are Leonard (1525–1563) and Thomas Digges (1546–1595), father and son (and please remember to keep prefacing those circas to many of the dates), William Gilbert (1544–1603, better known for describing the Earth as a giant magnet, like a sphere of lodestone), and Giordano Bruno (1548–1600), best known of all, more for of his leaving of life than for what he did during it. Bruno’s solar system had earth and other planets orbiting the sun (but was not entirely Copernican), and just one of innumerable suns and earths, all inhabited.

Don’t forget Tommaso Capanella (1568–1639), a near-exact contemporary of Galileo, who asserted the propriety of investigating innumerable, non-geocentric worlds in infinite space. He wrote in Italy in 1616, but published in 1622 in Germany. He appears to have outranked Bruno in people skills. Among the next generation of must-mention astronomers, Galileo was inclined, but not strongly, toward an infinite universe, Kepler as noted above definitely denied it, and Newton accepted.

Infinite universes with countless planetary systems gradually became commoner among natural philosophers and their ilk. The two whose multiple worlds would seem to be most absolutely separated from one another are Descartes (1596–1650), because his vortices hold together individual systems (rather than gravity), but would surely repel each other, and Thomas Wright (1711–1786). His “Plate XXI” appears in nearly countless introductory astronomy texts as a “prediscovery” of the disk shape of the Milky Way, within which it looks as if an intrepid voyager might venture from sun to sun. But this is merely the first stage of Wright’s multiply-structured cosmos and is really part of a very large thin spherical shell, surrounding a moral central cluster was the only possible habitat of life and mind. And thereby constitute habitable universes, of which ours is one and forever unreachable from the others.

But unique, finite worlds do not disappear. One of the strangest belonged to Alfred Russell Wallace (1823–1913, see Gould 1985). The arrangement of the stars, a central cluster with rings around it, resembles the contemporary picture given by Eddington and others, but according to Wallace, the position of the sun near the outer edge of the central cluster was the only possible habitat of life and mind in the universe. A little too much fine tuning, one might say.

6  Types of multiverse: IV. General relativistic and beyond

The advent of general relativity and Hubble’s announcement of his velocity-distance relation changed the rules of the game yet again. The first cosmic solutions to the Einstein (Einstein-Hilbert if you wish) equations, from Einstein himself and Friedmann (1922) were homogeneous. But Tolman (1934b) considered a very inhomogeneous case that would put our universe out of touch with other subsystems, not all of which were necessarily expanding. These were later known as Tolman-Bondi models, presumably because the first proposal was in a paper by Lemaitre (1933). There is a somewhat similar, but fictional, multiverse that is the setting for Olaf Stapledon’s (1937) “The Star Maker”, in which a creator devises universes of ever-increasing complexity (including a form of quantum mechanical many-worlds), inaccessible to each other, but all known to the Star Maker himself and to the narrator, who claims to be describing a dream. If you enjoy hearing other people talk about their dreams, you will probably like this book.

A plausible extension of exceedingly inhomogeneous relativistic models takes us to universes that actually bud off from a previously existing space-time. Among those who considered this possibility were Giovanelli (1963, an Australian solar astronomer, not related to the Cornell radio astronomer) and Pachner (1965, and earlier papers in the Polish literature). Hoyle’s (1965) thought that the constants of nature are likely to be different in different, widely separated, places probably goes with these.

It is not particularly easy for most of us to visualize non-communicating 4-spaces, so I would like to suggest a
coupole of 2-d analogies. First is the sort of Penrose repetive tiling which seems to consist of a large number of (not always identical) unit patterns, with their backs turned toward each other. Some Turkish and Persian carpet patterns give the same impression, as does the wallpaper in the main bedroom in the Lincoln house in Springfield, Illinois. (The chamber pot is, of course, a unique, almost closed space.)

A second analogy is suggested by the punch line of the elderly cosmology joke, “I’m sorry young man. It’s turtles all the way down.” That is, each universe is the almost flat (2-space) back of one of many turtles, piled up in a third dimension, so that you cannot climb from one to the next (see Yertle the Turtle, by Dr. Seuss). Hugh Everett’s (1957) many-worlds interpretation of quantum mechanics probably belongs here as being at least as difficult to imagine, though several delightful science fiction stories are built around it (and the possibility of very rarely sneaking from one branch to a nearby one).

The modern era opened explosively (at least by the standards of the first 2500 years of the topic) with the concept of inflation as a cure for various problems that most astronomers had never realized we had, including monopoles, causality or horizons, flatness, and origin of the fluctuation spectrum. Aluminum siding applied to houses is somewhat similar. Exactly how many people, and who, should be credited for inflation has varied among the givers of several prizes, but in 20 or so years from the first murmurings of 1979–1981, the number of inflationary theories had reached about 112, according to a 2002 table prepared by E. Sherald for a conference that year.

A subset of these more or less predict multiverses. Because this discussion had its origins in what was supposed to be an invited presentation at a conference honoring the 60th birthday and retirement of Katsuhito Sato, I mention only Sato et al. (1982) of the enormous relevant literature.

The idea that our particular subsystem is unexpectedly habitable (anthropic principle) has a slightly longer history than inflation. An association with multiverses is not logically necessary, but fairly common (chapters in Carr 2007). The mere mention of the phrase drives some of our colleagues to the same sort of non-linearity with which Herbert Dingle greeted the steady state universe, saying that you should not call a spade a perfect agricultural implement.

**7 The settled issues**

In chronological order, the scientific community has come to agree (a) that the Sun is a star, and a fairly common sort, (b) that the Milky Way is neither unique nor unusual, and (c) that many other stars have planets (one to five each, so far) orbiting them.

“Stars are suns” flits through several of the Greek speculations and is explicit in the writings (and drawings) of John Digges and Giordano Bruno shortly before 1600 (Danielson 2000). The idea became an awkward one in combination with heliocentrism when the limits on parallax became tighter and tighter. The difficulty was seen most acutely by Kepler, for whom bright stars like Sirius had apparent angular diameters not much smaller than a full Moon. He understood that this dropped to an arc minute or less for people with better eyesight and early telescopes. But, even so, a self-luminous body with an angular diameter of 30′ and a parallax less than 1′ is necessarily half an astronomical unit across, quite unlike our Sun. Indeed the situation could not sort itself out until the best telescopic stellar diameters of a bit less than 1′ were correctly blamed on atmospheric seeing, and stellar distances of parsecs were more fully accepted, which brings us well into the 18th century and the company of James Bradley (of aberration fame).

The Sun as an “average” star also takes a bit of parsing. A sample of nearby stars includes only a couple (Alpha Centauri and Sirius) as intrinsically bright, and the naked eye stars include only a couple (again Alpha Cen) that are as intrinsically faint.

What of the Milky Way? The phrase “island universe” (or rather its German equivalent) and the first strong argument for the correctness of the concept, in an infinite whole, belongs to Immanuel Kant in 1755. Arguments pro and con occupied the next almost 170 years. Part of the problem was that the word “nebula” in fact concealed at least three different sorts of entities – unresolved star clusters in the Milky Way, gas clouds in the Milky Way, and much larger extragalactic assemblages of stars and gas. Thus at various stages, Herschel thought he had shown that “all” nebulae were resolvable into stars, while Huggins thought he had shown they were “all” gaseous.

Hubble in 1929 naturally tied his distance scale to that established by Harlow Shapley a few years before, and so deduced that $H \approx 500$ km/s/Mpc. (Edwin P. did not dub it the Hubble constant, though we don’t suppose he would have objected.) This gave extragalactic nebulae (galaxies was Shapley’s word) sizes much smaller than the 50 kpc or more diameter claimed by Shapley for the Milky Way. The gradual shrinkage of $H$ from 1929 to about 1976 gradually reduced the Milky Way to normalcy by expanding the others.

As for planetary systems orbiting other stars, astronomers with Kant-Laplace images of solar system formation from a rotating disk, had always expected to find them (and quite often did, at least briefly). The Chamberlin-Moulton alternative of planet formation from stellar collisions, which would have made us the only game in town, had long since been abandoned when the first incontrovertible evidence for exoplanets appeared in 1992 (with a pulsar at the center) and 1995 (with a sun-like star at the center). This is history only to the very young.

**8 Conclusions: unanswered questions and the future**

Given the firm positive answers now in place for the questions of existence of other suns, other galaxies, and other...
planetary systems, the two residual issues (that is, roughly, Nobel Prize opportunities) fall at the extremes of astronomical length scales. First, are there other planets very much like our Earth? And, second, are there other large, unobservable space-times, perhaps very unlike our Universe?

Making progress on the first is a matter of new and better technologies and hard work; and the newer, better, and harder become increasing challenges as you define “like” more narrowly. Plausible stages include (a) orbiting a star of roughly solar mass, age and composition (already done), (b) roughly earth-like in mass, composition, and distance from host (perhaps achievable by Kepler and/or the next generation of ground-based searches) (c) possessed of both liquid water and gaseous volatiles over a solid surface, (d) life-supporting gases (perhaps water vapor, carbon dioxide, nitrogen) in the atmosphere, (e) plate tectonics, a moon, and magnetic field, (f) a Jupiter out there somewhere for shielding, (g) biogenic gases (molecular oxygen, ozone, methane, especially co-existing) in the atmosphere, and photosynthetic compounds on the surface, (h) slime molds, and (i) politicians in a biosphere. Ollivier et al. (2009) provide very nice discussions of most of these and of current and foreseeable searches. Not quite all of (a) to (i) are clearly essential, and at least the earlier items should be settled within decades or less.

Making progress on the second, large scale, question is much trickier. If a space-time is disjoint from ours, how can we learn even of its existence, let alone something of its properties, like different laws and constants of physics, perhaps even different dimensionality. A not infrequent reaction to this difficulty is a loudly stated “multiverses (and quite often also anthropic considerations) aren’t science!!”

But then critics have been hollering that cosmology isn’t science for as long as the concept has existed, partly because early models could account for almost any set of data, and, with only one universe to study, it was difficult to know what to do about standard scientific tests along the lines “how does the result differ if you change one input parameter at a time?” I remain convinced that steady state, by providing a fairly narrow set of (falsifiable) predictions, made cosmology a science, an opinion that never seems to please either its opponents or its last adherents, but see Kragh (1996), who also touches on a few sorts of multiverses, including quasi-steady-state near the end.

More recent multiverses can, perhaps, be subjected to various likelihood tests and to the possibility that some particular concept from theoretical physics, whose other predictions have been largely verified, also predicts multiple universes. Something of the sort has been claimed for some of the many flavors of inflation. It is probably not a coincidence that the most readable books have been pro-multiverse. My favorites include Vilenkin (2006), Suskind (2006), and the now venerable Rees (1997). Several points of view, for and against several sorts of multiple universes are represented in Carr (2007). Rapid observational progress on the modern multiverses issue seems less likely than in the case of earth-like planets, though it is guaranteed that theoretical fashions will change. My own view is the historically-conditioned one that, so far, every time some folks have supported and others opposed the existence of entities beyond our own (planets, suns, galaxies, groups and clusters of galaxies, planetary systems), the supporters have been more nearly right than the opponents. Thus I’m willing to bet small sums in favor of some sort of “more than just ours” again this time around.

Acknowledgements. I am indebted to Jun’ichi Yokoyama and Kat-suhito Sato for organizing and providing the motivation for the RESCEU Symposium in November, 2008, at which I was originally invited to speak on this topic. When I was a child, I was taught that one agreed to come to events, like family dinners, “G’d willing and the creek don’t rise.” The modern equivalent invokes the Transportation Safety Agency and one’s favorite airline.

References

Boltzmann, L.: 1895, Nature 51, 483
Bonner, W.B.: 1954, ZA 20, 169
Cantor, N.F.: 2001, In the Wake of the Plague, Harper
Carr, B.: 2007, Universe or Multiverse?, Cambridge Univ. Press
Crowe, M.J.: 1994, Modern Theories of the Universe from Herschel to Hubble, Dover
Friedmann, A.: 1922, ZPhy 10, 377
Friedmann, A.: 1924, ZPhy 21, 326
Hoyle, F.: 1965, Galaxies, Nuclei, and Quasars, Harper & Row
Tolman, R.C.: 1934b, *PNAS* 20, 169