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Trimble, V

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The Quest for Other Worlds, 350 BCE to 1995 CE

Virginia Trimble

Physics Department, University of California, Irvine, CA 92697
and
Department of Astronomy, University of Maryland, College Park, MD 20770

Abstract. The concept of aperoi kosmoi (multiplicity or plenitude of worlds) has had at least four meanings at various times, two capable of yielding images and two not. We explore here the several meanings and their connections with modern astronomical ideas, focusing finally on the one in the minds of the organizers of the present conference. There seem to be at least two dozen ways of potentially detecting or limiting the incidence of "other worlds," in the sense of potentially habitable planets orbiting other stars, a handful of which have led to detections, false alarms, or both.

INTRODUCTION

In the Fourth Century BCE, Epicurus taught that there are an infinite number of worlds both like and unlike ours, and Aristotle taught that there is only one. Neither hypothesis can currently be falsified. Both had in mind entire universes, with a center to which everything should fall, each observable only by the inhabitants thereof (else how should they know which center to fall toward), and Aristotle’s objection was a logical one focused on the impossibility of multiple centers (Dick 1982). When the theologians Roger Bacon and Thomas Acquinas reconsidered Greek ideas around 1250 and rejected plurality, this was the concept they had in mind. For all of them, a “world” would be centered on an “earth.”

The modern descendent of Epicurian other worlds would seem to be the universes of self-reproducing inflation and the like, in which we may be merely one of many (or infinitely many) four-dimensional space-times, embedded in higher dimension space and apparently without the possibility of communication among them (Rees 1997, 1999). This concept cannot reasonably be expected to result in pretty pictures of the other worlds or universes, though one might be able to imagine some of their properties by deducing the consequences of different values for the constants of nature from the ones in our universe.

The second pluralistic concept is the possibility of worlds succeeding worlds in temporal succession. This was considered positively by Origen in the 3rd century CE, somewhat negatively by Buridan, of whom more shortly, and again positively by Oresme in 1277. So far, nobody mentioned has gotten into serious trouble by discussing these ideas. Modern descendants are of two sorts. First, an oscillating (big bang - big crunch) universe, in which the same matter and energy participate repeatedly. This is not possible within the framework of general relativity (or any other metric theory of gravity within
which trapped surfaces form) as long as all the stuff has positive energy (as does all the stuff we know about, even the dark energy with its negative pressure). Second, the ekpyrotic and brane cosmologies, in which higher-dimension branes collide and bounce repeatedly. Essentially all of the stuff in each cycle belongs to that cycle, so that we cannot, in effect, communicate with those before or after, but some entropy perhaps carries over so that an infinite series is not possible. Again, no pictures.

The third, illustratable, concept is that of the moon, sun, and perhaps planets of our own system being habitable and inhabited worlds. This belongs almost entirely to the post-telescope era, but appears third because Lucian of Samosata wrote in the Second Century CE a *Vera Historia* of a voyage to the moon, intended primarily to explore terrestrial foolishness (Dick, 1982, Guthke 1990).

Fourth is the idea of other systems like ours and potentially detectable. Initially these were earth-centered and regarded favorably from about 1330 within the Catholic Church tradition. Proponents reasonably well known (e.g. Dick 1982) include John Buridan (ca. 1295-1358) of Paris, remembered for his parabolic ass, who starved half way between two equally desirable piles of hay, unable to make a decision between them, and William of Occam or Okham (ca. 1280-1347), who was probably bearded, despite his razor. So obscure as to have missed Dick’s eagle eye was a certain Bradwardine, also educated at Oxford, who wrote around 1330 in favor of plurality (but without taking a stand on whether there were inhabitants or salvation elsewhere), and, remaining unpublished until many years later, was elected Archbishop of Canterbury in 1348, shortly before succumbing to the plague (Leff 1984). Their worlds were earth-centered. After Copernicus came Giordano Bruno and Thomas Digges advocating planets in orbit around other stars shortly before 1600. Digges died peacefully in 1595, Bruno less so in 1600. For what it is worth, the pioneering author (and translator of Fontenelle) Aphra Behn was perhaps the first woman to deny Copernican plurality in 1686, and Fanny Burney, the author of *Evalina*, the first to affirm it, in 1786. Still a century later, Maria Mitchell, the first American woman astronomer, declared that more data were needed.

Finally, if our goal is really other earths, then we must ask what it takes to make an earth-like planet. A solid body, presumably, (so you will have someplace to put your car keys), but with air and water. These require both the presence of volatiles and location within the fuzzily-defined habitable zone of a star not too different from the sun. Third, perhaps, tides, to permit tide pools. Is the sun enough, or would you also like a moon? The latter also comes in handy in helping to stabilize the rotation axis of its parent planet. Though Mars at the moment is only a bit more oblique than Earth, it is said to be capable of lying on its side from time to time.

Mantle convection and plate tectonics are useful for preserving a mix of land and water, and also in due course for producing ores and fossil fuels. Required are at least radioactive heating or melting of the core from kinetic energy of accumulation and (apparently, from a comparison with Venus) either rapid rotation or liquid water to cool descending slabs, or both. Magnetic fields for protection from solar energetic particles again require a molten core and rotation (compare both Venus and Mars). You might want a Jupiter (large mass, further out) to clear out debris and protect from excessive bombardment. But the ultimate earth-like signature would be the presence of chemically-based life, potential evidence for which was discussed by Seager during the conference.
Here we encounter the first false alarms. Galileo described the mountains and craters he had seen on the moon as implying the moon might be earth-like. It took Kepler, rushing in within weeks of seeing a preprint of *Sidereus Nuncius* to declare the round craters to be circular embankments in which the lunar inhabitants had dug their cave dwellings. Indeed he had written in a proto-science-fiction mode of an inhabited moon beginning still earlier, though his *Somnium* was published only posthumously in 1634. Kepler’s moon had a moist atmosphere (hence the smooth appearance of the limb, despite the mountains and craters), and he credited observational evidence for rain there to his teacher Michael Maestlin.

By 1650, the idea of the moon and sun as inhabited worlds was common. But our favorite narrator is Cyrano de Bergerac (no, and nose, he was not just an invention of Edmund Rostand), who wrote in 1687, with accompanying wood cut, of a voyage to these other worlds, powered by a giant dew drop (he rode inside) that, like smaller dewdrops, rose at dawn. He was perhaps the last spacecraft designer to use his own invention.

The 1686 *Entretiens sur la pluralité des mondes* of Bernard le Bovier de Fontenelle was perhaps the most influential work in this tradition, helped by his living 71 years beyond its publication (50 of them as perpetual secretary of the Academie des Sciences) and by translations into English and other languages. His illustrations are so romantic that the long eyelashes suggest a gal in the moon rather than a man.

The last mainstream astronomer in this lunatic tradition was William Herschel, who began sketching the moon in 1776 (Crowe 1986). He has understood that the atmosphere of the moon must be much sparser than that of earth (or the limb would not look so sharp), but he remained convinced of the presence of inhabitants, centered around the circular structures and drew what he described as giant forests in their vicinity. I have seen Herschel’s lunacy described as a deliberate hoax, but, though he never published the forest sketches, he took them seriously enough to write to Neville Maskelyne, the Astronomer Royal.

A century ago, the best-known inhabited world was Mars, with the canals, oases, seasonal agriculture, and all the rest of Giovanni Schiaparelli (1835-1910), Percival Lowell (1855-1916), and, less famously, William Pickering and others, though the opposition was nearly equally famous. Some exciting science fiction arose from these canals (*War of the Worlds*, Edgar Rice Burroughs, C. S. Lewis’s *Out of the Silent Planet*, etc.) but they fell out of fashion, and disappeared forever in the cratered surface revealed by the first orbiter images. The human predisposition for pattern recognition had been carried to excess. Less well known and still more illusory were Lowell’s Venusian canals. At least one of the drawings appears to be the pattern of blood vessels at the back of an eye, reflected in the lens of a telescope stopped very far down to accommodate a very bright object.

Incidentally, the very recent Galileo spacecraft images of cracks in the ice on Europa do not, without some advance instruction, look all that different from the Martian and Venusian drawings. At least no one seems to think them artificial, and they are clearest in the best images, not the most fleeting.
WORLDS OUTSIDE THE SOLAR SYSTEM

The parallel track of thinking about plurality elsewhere is marked mostly by images that look increasingly like modern images of stars and galaxies. Bruno's 1591 diagram is simply spheres of influence with letters marking their centers and the points where a test particle might have difficulty deciding which way to fall. Apparently he had in mind much larger separations between (planet-centered) worlds than could be shown on even folio paper. Descartes tesselated the universe into vortices in 1644, and Henry Regius in 1654 enhanced a Copernican diagram by putting at least one planetary orbit around each star in the "sphere of fixed stars," still apparently finite. Digges's stars extended explicitly to infinity (thought he too had the small-paper problem in drawing this), and only the caption tells you that they have their own planets.

A century later, Thomas Wright who appears most often in modern books for having drawn the Milky Way as a slab rather than a sphere, provides a close up, in which the spheres of influence of the sun, Sirius, and Rigel are all the same size (with others lurking in the background), and separated by distances not too much larger than their sizes, so that communication might not be impossible. Each system has a few circular planet orbits and some highly eccentric comets. An 1821 edition of Fontenelle once again has the solar system bigger than any of the others, as well as in the middle. Indeed the plurality issue remains somewhat entwined with the question of the location of the center of the Milky Way (often then thought of as the entire universe) until the work of Harlow Shapley between 1918 and 1922 moved us firmly to the outskirts of a very large galaxy (shown soon after by Edwin Hubble to be merely one of many).

It is perhaps not unexpected that Alfred R. Wallace (Darwin's pacer) might think of using a central location to claim that the earth was uniquely habitable and inhabited. Darwin, however, was a pluralist, and Arthur Eddington, who drew a very similar Milky Way at much the same time (1912 to Wallace's 1903) could envisage a central star cluster and ring around it without insisting upon anthropocentric implications. Their ring, incidentally, was more or less Gould's belt of OB stars, not the sort of ring or arc recently found and attributed to a torn up companion galaxy.

A last barrier to plentitude was the Chamberlin-Moulton hypothesis for the formation of the planetary system. Through most of the 18th and 19th centuries, most scholars had imagined something like the Kant-Laplace nebular hypothesis, in which the planets (etc.) arose from a disk of residual material around a star as it formed. This would make planetary systems common. Indeed there was a school of thought that identified the spiral nebulae as such systems in formation. A serious physical objection to this picture was that it would seem to imply that the sun should contain its fair share of the angular momentum of the solar system, instead of 99.9% of the mass, but only 1% of the angular momentum. Much of this disparity we now blame on the gradual slowing of solar rotation by the solar wind, much more powerful in the past.

But to Chamberlin and Moulton (and later Jeans, Jeffreys, Lyttleton, and others), it meant that the material to form the planets must have been dragged out of the sun by a close stellar encounter. If so, then there might be only one or a few systems in the whole Milky Way, since such encounters are rare (it's a long way between stars).

The tidal encounter hypothesis began to go out of fashion in the 1940s, because it is hard to make the hot stuff condense as required. Using modern data, we know that the
presence of deuterium in the planets means their substance can never have been inside
the sun, where all the deuterium long ago fused to helium. But the prediction of planetary
rarity did not actually keep people from looking in the early years of the 20th century
or, indeed, from announcing that they had found planets orbiting other stars.

**RECENT HISTORY - SEARCH AND DETECTION STRATEGIES**

The table shows the most complete list I have been able to compile of methods whose
success or promise has been claimed in the (more or less) refereed literature. A few
were actually added in the course of the conference (evaporated comets, X-ray flashes
from planetary collisions). References are given for only a few of the less well known,
and the meanings of the codes F, T, ?, and * are briefly explained again at the foot
of the table. Less succinctly (and the opinions are not necessarily those of the editors,
all participants, or a majority of the total community), the F’s are false alarms. That
is, someone published an announcement of one or more planets found in the tabulated
way that later turned out to be something else (often though not always underestimated
errors). This does not preclude real planets having been found by the same method
later. The T’s I regard as observations truly indicative of planetary mass objects in
orbits around solar-type (mostly) stars. The ?’s indicate real astronomical phenomena for
which other explanations are possible. In some cases (Mira variables) I think the others
are much more probable. In other cases (gaps in disks around young stellar objects,
much discussed at the conference) planets may well be the most likely explanation.

**Table: Search and Detection Methods**

1. Direct imaging (F)
2. Periodic residual in proper motion (F, T)
   *3. Periodic variation in pulsar period (F, T)
   *4. Periodic variation in radial velocity (F, T)
   *5. Transits (T)
6. Perturbation of line profiles by planetary atmosphere (?)
   *7. Blips in microlensing light curves (T)
8. Gaps in YSO accretion disks (?)
9. Warps in YSO accretion disks (?)
10. Collimation of bipolar ejecta (?)
11. Pollution of host atmosphere (F)
12. Distortion of times of CBS eclipses (gravitational effect, not transit, F?)
13. Nova-like outburst of V838 Mon as AGB swallowing planets (?, R1)
14. X-ray or gamma ray bursts as collisions (?, R2)
15. OH, H$_2$O in evolved carbon star (?, R3)
16. Embedded planet in RG atmosphere mimics Mira pulsation (?, R4)
17. Masers in planetary atmospheres, vs. host stars (?)
18. Zodiacal light
19. Independent confirmation of panspermia
20. Success of SETI
21. Incredible luck with Pioneers or Voyagers
22. GRBs as exhaust from spaceships: 4-d lines of events with 511 keV features (R5)
23. Arrival of LGMs
24. Something even more outlandish

F: False alarms  T: Real detections
*: Discoveries  ?: Phenomenon exists; planetary connection uncertain

R5: Harris (1990)

The *'s mark techniques that have led to discovery of one or more planets where none was previously known. Notice that not all T’s are *’s (and indeed not all snarks are boojums). Notice that “pollution of host atmosphere” is marked F. Clearly some planets do migrate to destruction and this will increase their (former) hosts’ surface metallicity. But, as emphasized by Fischer and others at the conference, this is not the dominant effect. Host stars were relatively metal-rich to begin with.

The story of the successes really belongs to the rest of the conference, so we begin here with the others. The title of King of the False Alarms (indeed arguably King of Frauds) surely belongs to Thomas Jefferson Jackson See (1866-1962), who spent the last 60 years of his life in scientific exile (largely on Mare Island) but received a fairly nice tribute in Sky and Telescope. In 1897, he announced (in Atlantic Monthly!) that he had actually imaged planets around some nearby stars, though he never said which ones, and, curiously, his intent seems to have been to demonstrate the uniqueness of our earth and solar system. This claim never reached the astronomical literature, but his discovery of a planet orbiting the secondary star of the visual binary 70 0ph did (See 1896). So acrimonious, however, became his disputes with doubters that the pages of AJ and other standard journals were soon closed to him. He argued for the rapid rotation of Venus (true anyhow for its atmosphere) and against the Chamberlin-Moulton hypothesis (false, though not for his reasons) and has had mild cult status, like Velikovsky, at times.

Curiously 70 0ph B was one of the two stars (the other was 61 Cyg) for which Kaj Strand recorded a false-alarm planet in 1943. His announcement, like that of See, was based on small deviations in proper motion from the expected orbit. Best known in this balliwick is Peter van den Kamp, who gave proper motion planets to Barnard’s star and Lalande 21185 in 1944 and upped Barnard’s star’s allotment to two in 1963. Most of us have heard at least a folk-tale version of the problem with the Sproul Observatory discoveries, which was that the telescope had been disassembled in 1949 and reassembled with some slight difference in the alignment which then mimicked periodic residuals.
George Gatewood of Alleghany Observatory and Heinrich Eichhorn of the University of South Florida were instrumental in showing that the Sproul results could not be duplicated for either star. Curiously, Gatewood (1996) later put forward another very tentative planet for Lalande 21185 which has also not been confirmed.

Even the two radial velocity methods, the pride of our discipline, have had their junior moments. Campbell et al. (1988) reported periodic velocity residuals with periods of a few years and amplitudes of 10’s of m/sec for more than half the solar-type stars examined, including ε Eridani, object of the first SETI search. Some combination of variable star activity and under-estimated error bars seem to have been responsible. Implied masses were a few jupiters.

Most recent and so best remembered is the timing residual for psr 1829-10 reported by Bailes et al. (1991). Dozens of models were in press before the authors announced that the six-month period was due to a planet all right, but the planet was earth, whose orbital eccentricity had not been correctly removed from the data. Those models then acquired the status of predictions and were ready and waiting when Wolszczan and Frail (1992) announced the first two (of three) terrestrial mass planets orbiting the millisecond pulsar 1257+12. Lightning has not really struck again. The only other strong pulsar-planet candidate belongs to a binary pulsar in a globular cluster.

But we are always ready and waiting for the next good chance. As early as 1920, Scientific American published a grid-type drawing to be radioed in dots and dashes to some promising life-host planet as soon as one should be discovered. The image resembles the plaque actually sent with the Pioneer spacecraft, except Carl and Linda were better looking.

On the side of the successful methods, only pulsar timing and distortions of MACHO light curves (methods 3 and 7) can currently reveal masses as small as that of the Earth, though transits and proper motions measured from space someday should. As for discoveries within our own solar system, Uranus was found by direct imaging, Neptune (and to a certain extent Pluto) from proper motion residuals, and Vulcan from transits, of which several were reported soon after Leverrier announced the anomalous advance of the perihelion of Mercury. Motion of the earth was actually discovered as aberration of starlight, a special relativistic effect, but later from annual variations of radial velocities.

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