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Successful Predictions of Three Stellar-Scale Enigmas

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Recent observations suggest that pulsars can have planetary systems, that the Galaxy is populated by MACHOs with an average mass on the order of $0.1 M_\odot$, and that the stellar mass function has a cutoff just below $0.15 M_\odot$. Each of these findings is at variance with conventional astrophysical assumptions. On the other hand, a fractal cosmological model predicted all three stellar-scale enigmas.

1. INTRODUCTION

The new cosmological model discussed herein is the Self-Similar Cosmological Model (SSCM). Its motivations, conceptual content, predictions, and open questions have been reviewed previously (Oldershaw, 1989a,b). Very briefly, the new fractal paradigm views the nested hierarchical organization of physical systems as a fundamental, statistically unchanging property of nature rather than as a secondary by-product of gravitational interactions. It is proposed that this hierarchical order extends well beyond upper and lower observational limits, and may be entirely without spatiotemporal bounds. It is noted that the observable portion of the cosmological hierarchy can be divided naturally into discrete scales, i.e., the atomic, stellar, and galactic scales, wherein only a few classes of objects from each major scale dominate in terms of abundance and collective mass. For example the mass spectrum of the atomic scale is dominated by e^-, p^+, and He^{2+}. A principle of self-similarity states that each primary class of objects constituting a given scale has an analogous counterpart on every other scale. Lengths (R), temporal periods (T), and masses (M) associated with analogous systems from neigh-

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boring scales n and $n - 1$ are related by the following heuristic scale transformation equations:

$$R_n = \Lambda R_{n-1} \tag{1}$$

$$T_n = \Lambda T_{n-1} \tag{2}$$

$$M_n = \Lambda^D M_{n-1} \tag{3}$$

where Λ and D are dimensionless constants that have been empirically determined to be $\sim 5.2 \times 10^{17}$ and ~ 3.174, respectively. In general, the degree of self-similarity for fractal structures can vary from exact to weakly statistical. Empirical evidence suggests that the actual cosmological self-similarity is more toward the exact end of the range, with measured departures from exact self-similarity usually being less than 20% (Oldershaw, 1987, 1989a,b). At present the SSCM should be viewed as natural philosophy: a conceptual framework based on hierarchical and self-similarity principles, and a quantitative set of heuristic scaling rules. However, even in this preliminary state the model is able to generate definitive predictions that can verify or falsify the agreement between paradigm and nature. Fractal systems abound in nature (Mandelbrot, 1983) and the concept of hierarchical organization in which parts are analogous to wholes has a long history in science, [e.g., Kant, 1755; Charlier, 1922; de Vaucouleurs, 1970; etc.], so the fractal model of the universe, while unorthodox, is not without theoretical precedent or substantial empirical justification.

In the past several years three empirical enigmas pertaining to the stellar scale of nature's hierarchy have been discovered. The unexpected existence of pulsar/planet systems has been confirmed (Thorsett, 1994), an enigmatic population of Galactic MACHOs (massive compact halo objects) with $\langle M \rangle \approx 0.1 M_\odot$ has been identified (De Paolis *et al.*, 1995), and an apparent cutoff in the stellar mass function (SMF) just below $0.15 M_\odot$ has left many baffled (Travis, 1994). The SSCM predicted each of these three surprising results, and can explain them without *ad hoc* adjustments to the model. In this paper the three apparently successful predictions will be discussed.

2. PULSAR/PLANET SYSTEMS

The first example of a new class of objects, in which pulsars are orbited by planets, was discovered by Wolszczan and Frail (1992). Currently at least three pulsar/planet systems have been observed and so it appears that a genuine new class of systems has been identified (Thorsett, 1994). Although a considerable number of *post facto* models for the origins of these systems have been proposed, their discovery was definitely not anticipated by stellar evolution theory or any conventional cosmological model.

On the atomic scale of the cosmological hierarchy one can find a general class of "planetary atoms" in very high Rydberg states (Richter and Wintgen, 1991). These atoms and ions have no electrons left in the lowest energy states; instead the bare nucleus is orbited by a distant electron system that is quasiclassical (Richter and Wintgen, 1993), with localized particle-like properties (Yeazell *et al.*, 1993) and a tendency toward planar morphology. They are referred to as planetary atoms because they are at least roughly analogous to stellar-scale planetary systems (Metcalf, 1980; Wintgen, 1993). The principle of self-similarity asserts that the stellar scale should be analogous to the atomic scale and have a class of analogs in which ultracompact nuclear objects are orbited by planetary systems. This general prediction is intrinsic to the SSCM and constitutes a definitive test of the principle of self-similarity. The specific case of "[a]nalogues to hydrogen in states characterized by very high values of n and l . . . would consist of a stellar scale proton analogue orbited by an electron analogue that is distributed in a planetary system like that of the Solar System. Radii for the planetary distributions of these systems are expected to range from about 10^{12} cm to as large as 10^{14} cm, and extensive magnetic fields, reminiscent of those found in the Solar System, are to be expected. These analogues to highly excited hydrogen atoms would be difficult to detect since their nuclei are black holes and their planetary systems have very low luminosities" (Oldershaw, 1989b). The SSCM asserts that "atomic nuclei and stellar scale objects classified as neutron stars are self-similar analogues," and their radii, densities, and magnetic dipole moments make this unambiguous (Oldershaw, 1987). Therefore, the stellar analog of a transhydrogenic atom in a very high planetary atom state is predicted to have a neutron star as its "nucleus," rather than the hydrogen analog's $0.145 M_\odot$ black hole.

In sum, the SSCM clearly anticipated the enigmatic discovery of pulsar/planet systems and their basic physical characteristics, to the extent that these have been accurately elucidated. It further predicts that the stellar-scale analog to hydrogen in a high Rydberg state, as quantitatively characterized above, will be identified through microlensing searches.

3. THE AVERAGE MASS OF GALACTIC DARK MATTER OBJECTS

Perhaps as much as 99% of the matter comprising the atomic scale of the cosmological hierarchy is in the form of highly ionized plasma and, for objects possessing rest mass, e^-, p^+, and He^{2+} particles dominate the atomic scale in terms of numerical abundance and collective mass. In accordance with the principle of self-similarity, therefore, stellar analogs to e^-, p^+, and He^{2+} must dominate the stellar scale in a similar fashion. Using equation (3) one can calculate masses of ~7 × $10^{-5}M_\odot$, ~$0.145M_\odot$, and ~$0.58M_\odot$ for these analogs, respectively, and it is obvious from their predicted radii that they would be ultracompact objects that emit relatively little electromagnetic radiation. In this manner the SSCM naturally retrodicts large quantities of dark matter, with 90–99% being the anticipated abundance range for the stellar scale. The new fractal model also "predicted [Oldershaw, 1987, 1989b] that 95% of the dark matter *must* be in the form of ultracompact objects with masses of 7 × $10^{-5}M_\odot$ and $0.145M_\odot$" (Oldershaw, 1993). The relative abundances for the 7 × $10^{-5}M_\odot$, $0.145M_\odot$, and $0.58M_\odot$ subpopulations should be roughly 54%, 41%, and 4%, respectively, of the total number of stellar-scale dark matter objects. The SSCM predicts that no other subpopulation of MACHOs or WIMPs accounts for more than 2% of the currently inferred dark matter.

The specificity of the above-mentioned retrodictions and predictions regarding the dark matter is unusual in the field of cosmology today. To its credit, the SSCM makes *definitive* predictions (Oldershaw, 1988) which allow its basic principles and assumptions to be unambiguously verified or falsified either at present or in the near future. The prediction-generating scaling equations of the new fractal model have not been "adjusted" since their derivation in 1985.

The first two dark matter candidates were identified by microlensing (Einstein, 1936; Paczynski *et al.*, 1986) of distant quasars by stellar-scale constituents of a galactic lens. The estimated masses for these candidates were ~5.5 × $10^{-5}M_\odot$ (Webster *et al.*, 1991) and ~$0.1M_\odot$ (Flam, 1992), in good agreement with SSCM predictions. While it cannot be guaranteed that the microlenses were dark matter objects, if it can be shown that galactic dark matter is comprised of massive compact objects, as evidence discussed below suggests, then this population would be 10–100 times more likely to cause the events than known populations of luminous objects. Not long after this, the MACHO (Alcock *et al.*, 1993), EROS (Aubourg *et al.*, 1993), and OGLE (Udalski *et al.*, 1993) collaborations began impressive efforts to observe microlensing of distant sources by intervening dark matter objects within the Galaxy. The first strong candidate event to be found was associated with a mass of $0.12M_\odot$ (Alcock *et al.*, 1993), which again was statistically indistinguishable from the SSCM prediction of $0.145M_\odot$. Two further microlensing events were identified by Aubourg *et al.* (1993), but their masses were more uncertain: the range of $0.03M_\odot$ to $1M_\odot$ was cited. When Jetzer and Masso (1994) applied a method of moments analysis to these first Galactic events the estimated average mass was $0.144M_\odot$! Subsequent to these results a wealth of data has been accumulated and partially analyzed. The MACHO collaboration alone has recorded over 50 events, mostly due to galactic bulge lenses, but uncertainties in detection efficiencies and theoretical modeling have dramatically slowed the publication of new results. Those with access to the available data set still quote a figure of ~$0.1M_{\odot}$ as the best current estimate for the average mass of the massive compact halo objects (De Paolis *et al.*, 1995).

Given the predicted abundance for the $7 \times 10^{-5}M_{\odot}$ objects, present observational programs would not have been expected to detect any of these proposed objects yet. The EROS group has been running a rapid sampling program to detect low-mass dark matter objects, but the present program would have to run for many years before a single member of the $7 \times 10^{-5}M_{\odot}$ population would be expected. However, if future observations should detect such a population, supporting the validity of the original ~$5.5 \times 10^{-5}M_{\odot}$ event, then this result would confirm that the SSCM has definitively predicted the major features of the galactic dark matter mass spectrum. The expected mass peak at $0.58M_{\odot}$ should emerge from the background, but, at a relative abundance of 4%, this will take some time. Even smaller predicted peaks at $0.29M_{\odot}$ and $0.44M_{\odot}$ should take even longer to emerge from the noise.

4. SMF CUTOFF JUST BELOW $0.15M_{\odot}$

Two research teams (Bahcall *et al.*, 1994; Paresce *et al.*, 1995b) have independently found evidence for a possible cutoff in the SMF just below $0.15M_{\odot}$. Using the refurbished Hubble Space Telescope to conduct faint star surveys of unprecedented sensitivity, Bahcall *et al.* (1994) looked at the low end of the SMF in the Galaxy, and Paresce *et al.*, (1995b) conducted a census of dwarf stars down to $0.1M_{\odot}$ in the globular cluster NGC 6397. The results, independently found by both groups, are best characterized by a figure prepared by Paresce's group (Travis, 1994). Rather than rising steadily to the lower limit of the survey, as anticipated on the basis of heuristic and theoretical grounds, the SMF rises to a peak at roughly $0.15M_{\odot}$ and then drops abruptly to the survey limit at about $0.1M_{\odot}$. Paresce *et al.* (1995a) report similar observations for M15 and ω Cen. Astrophysicists have as yet no explanation for the SMF cutoff or the significance of $0.15M_{\odot}$, the approximate turnover point.

As mentioned in previous sections, the mass value of $0.145M_{\odot}$ has a special status for the SSCM, which also predicts a comparatively barren region of the SMF between the strong peaks at $0.145M_{\odot}$ and $7 \times 10^{-5}M_{\odot}$. This fact is unambiguously intrinsic to the fractal paradigm and has been specifically discussed, as follows. "[A] related prediction is that there is a discrete mass spectrum for stars, in exact analogy to that for atomic masses. . . An unexplained cutoff (Waldrop, 1987) in the distribution of stellar masses below the lower limit of the M dwarf mass range is consistent with SSCM expectations" (Oldershaw, 1989b). In this manner the SSCM predicted, and can explain, the results of Bahcall *et al.* (1994) and Paresce *et al.* (1995b).

Also of interest is the fact that predicted peaks in the stellar-scale mass spectrum at $0.44M_\odot$, $0.58M_\odot$, $0.73M_\odot$, and $0.88M_\odot$ match up reasonably well with the peaks in a recently published histogram of masses for white dwarf stars in close binaries (Han *et al.*, 1995). It can be predicted unambiguously that large samples of accurate stellar mass values will consistently reveal mass peaks at values specified by the SSCM.

5. CONCLUSION

In the past few years the SSCM has been able to successfully predict three major observational findings that have no ready explanation in terms of conventional astrophysical models. Had the standard cosmological model—The Big Bang theory amended by the inflation hypothesis—predicted the three unique phenomena discussed above, then astrophysicists would have regarded these successful predictions as major scientific events. The truth of the matter is that other models failed to predict pulsar/planets, the average mass of the dark matter objects, and the SMF cutoff. Because so few astrophysicists are aware of the SSCM, let alone appreciate its conceptual elegance, analytical complexity, and potential for unification, it is important to make these prediction results known.

The beauty and seemingly infinite complexity of fractal geometry [e.g., the Mandelbrot (1983) set] are actually the product of a small number of underlying principles. This property of endless variation and self-similarity deriving from a few simple laws is highly appropriate to modeling nature. In light of recent discoveries, the SSCM deserves careful consideration and sincere efforts to elucidate its largely unexplored mathematical physics.

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