

Interpretation of the Helix Planetary Nebula using Hydro-Gravitational Theory

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ABSTRACT

Wide angle Hubble Space Telescope (HST/ACS) images of the Helix Planetary Nebula (NGC 7293) are interpreted using the hydro-gravitational theory (HGT) of Gibson 1996-2000 that predicts the baryonic dark matter and interstellar medium (ISM) consist of Mars-mass primordial-fog-particle (PFP) frozen H-He planets. The new ACS images confirm and extend the O'Dell and Handron 1996 WFPC2 images showing thousands of cometary globules, which we suggest are cocoons of PFP and Jupiter frozen-gas-planets evaporated by powerful beamed radiation from the hot central white dwarf and its companion. The atmosphere mass of the largest cometary globules is $\approx 3 \times 10^{25}$ kg with spacing $\approx 10^{14}$ m, supporting the prediction of HGT that the mass density of the ISM in Galaxy star forming regions should match the large baryonic primordial value at the time of first structure formation (10^{12} s), with $\rho \approx (3 - 1) \times 10^{-17}$ kg m⁻³.

Subject headings: ISM: structure – Globular clusters: general – Cosmology: theory – Galaxy: halo – dark matter – turbulence

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1. Introduction

By coincidence, the direction opposite to the peak Leonid meteoroid flux in November 2002 includes the closest planetary nebula (PNe) to the earth (150-200 pc $\approx 5 \times 10^{18}$ m) Helix (NGC 7293), so that the Hubble Helix team of volunteers could devote a substantial fraction of the 14 hour Leonid stand-down period taking photographs with the full array of HST cameras including the newly installed wide angle Advanced Camera for Surveys (ACS). As the closest PNe to earth with one of the hottest known central white dwarf stars (120,000 K) and close (dMe) X-ray companion (Guerrero et al. 2001) to powerfully beam radiation and plasma into their surroundings, Helix provides an ideal laboratory to test predictions of hydro-gravitational theory (Gibson 1996) and a quasar microlensing interpretation (Schild 1996) that the ISM of star forming regions of the Galaxy are dominated by primordial densities of baryonic dark matter in the form of frozen H-He primordial-fog-particle (PFP) planets from which all stars and planets have formed. According to HGT, most Galactic star formation occurs in primordial proto-globular-star-cluster (PGC) clumps of PFPs with baryonic mass density $\approx (3 - 1) \times 10^{-17}$ kg m $^{-3}$ reflecting the large mass density existing at the time of the first gravitational structure formation 30,000 years after the big bang.

Most of the \approx million PGCs in the Galaxy have diffused away from the central core to form the dark matter inner halo. From the HST/ACS images of the Tadpole merger, the inner halo is homogeneous and very large. Its 130 kpc radius is revealed by young globular clusters and stars triggered into formation by tidal forces and radiation from the merging galaxy (Gibson & Schild 2003a). Galactic star formation occurs in the disk. From HGT the disk is formed by accreting PGCs, so the interstellar medium of the disk should be that of a PGC; that is, trillions of frozen PFPs in metastable equilibrium with their evaporated gas at the high average baryonic mass density of the time of first structure, $\rho_B \approx 10^4 \times \langle \rho_G \rangle$, where the average density of the Galaxy $\langle \rho_G \rangle \approx 10^{-21}$ kg m $^{-3}$. From HGT it is no accident that the outer planets of the solar system are large and gassy and that the hundreds of extra-solar planets discovered are also large Jovians. Hot, central, PNe white dwarfs (generically with companion stars) form plasma beams and radiation that evaporate and photo-ionize surface layers of their invisible surrounding ISM of PFP frozen-gas-planets and their accretional Jovian descendants (JPPs) to large sizes and brightnesses so that their evaporated gas cocoons can be imaged and properties measured for comparison with theory. In this paper we compare the new HST/ACS Helix observations, plus other PNe observations, with hydro-gravitational theory and previously proposed explanations of cometary globule and planetary nebula formation.

According to HGT, gravitational structure formation began in the plasma epoch soon

after mass dominated energy at time 25,000 years with gravitational fragmentation of the plasma into $\approx 10^{47}$ kg proto-supercluster mass (baryonic and non-baryonic) clouds that further fragmented to proto-cluster and then $\approx 10^{42}$ kg proto-galaxy mass (baryonic) clouds just before the plasma to gas transition at 300,000 years. At that time, fragmentation scales decreased dramatically when the kinematic viscosity decreased from $\nu \approx 10^{25} \text{ m}^2 \text{ s}^{-1}$ for the primordial plasma to $\nu \approx 10^{13} \text{ m}^2 \text{ s}^{-1}$ for the H-He gas upon photon decoupling (Gibson 2000). An important prediction of HGT is that gravitational fragmentation occurred in the primordial plasma at length scales much smaller than the Jeans 1902 acoustic gravitational scale (Table 1) and that the more massive non-baryonic dark matter (possibly neutrinos) diffused into the voids to reduce the gravitational driving force. Thus, the non-baryonic dark matter did not clump to form cold dark matter (CDM) halos that further clumped to form potential wells for galaxy formation as predicted by the standard (but erroneous and misleading) cold-dark-matter-hierarchical-clustering cosmological (CDMHCC) model. Gravitational instability and structure formation begins from non-acoustic density nuclei at the smaller scales permitted by the smaller diffusivity of baryonic matter. Such density nuclei are absolutely unstable to gravity, and immediately grow or decrease in magnitude depending on fluid forces at the largest Schwarz scale, Table 1.

Proto-galaxies formed just before photon decoupling at 10^{13} s retain the baryonic density existing at the earlier time 10^{12} s of first structure ($\rho_B = (3 - 1) \times 10^{-17} \text{ kg m}^{-3}$) as a fossil of that event, and fragment simultaneously at the Jeans scale and the viscous Schwarz scale determined by the fossilized rate-of-strain ($\gamma \approx 10^{-12} \text{ s}^{-1}$) of the plasma at the time of first structure to form proto-globular-star-clusters (PGCs) and primordial-fog-particles (PFPs). Table 1 lists the critical length scales of primordial self-gravitational structure formation and their physical significance. Table 2 lists some of the acronyms used to describe the process of structure formation by HGT. A full discussion of HGT with comparisons to recent observations is available elsewhere (Gibson & Schild 2003b).

In the following we briefly review hydro-gravitational theory and some of the supporting evidence, and compare the predictions of HGT with respect to planetary nebula and star formation with standard models and the observations. Finally, some conclusions are offered.

2. Theory

2.1. Hydro-gravitational structure formation

Standard CDMHC cosmologies are based on ill-posed, over-simplified fluid mechanical equations, an inappropriate assumption that the fluid is collisionless, and the “Jeans swindle”

to achieve a solution. The Jeans 1902 theory neglects non-acoustic density fluctuations, viscous forces, turbulence forces, particle collisions, and the effects of diffusion on gravitational structure formation, all of which can be crucially important in some circumstances where astrophysical structures form by self gravity. Jeans did linear perturbation stability analysis (neglecting turbulence) of Euler’s equations (neglecting viscous forces) for a completely uniform ideal gas with density ρ only a function of pressure (the barotropic assumption) to reduce the problem of self-gravitational instability to one of gravitational acoustics. To satisfy Poisson’s equation for the gravitational potential of a collisionless ideal gas, Jeans assumed the density ρ was zero in a maneuver appropriately known as the “Jeans swindle”. The only critical wave length for gravitational instability with all these questionable assumptions is the Jeans acoustical length scale L_J where

$$L_J \equiv V_S/(\rho G)^{1/2} \gg (p/\rho^2 G)^{1/2} \equiv L_{JHS}, \quad (1)$$

G is Newton’s gravitational constant and $V_S \approx (p/\rho)^{1/2}$ is the sound speed.

The related Jeans hydrostatic length scale $L_{JHS} \equiv [p/\rho^2 G]^{1/2}$ is given in the equation and has been misinterpreted by Jeans 1902 and others as an indication that pressure itself somehow prevents gravitational condensation on scales smaller than L_J . Although the two scales appear to be equal they are not. The ratio $h = p/\rho$ in L_{JHS} is the stagnation enthalpy for a condensation streamline and is initially zero from Bernoulli’s equation. Non-acoustic density extrema are absolutely unstable to gravitational structure formation. Minima trigger voids and maxima trigger condensates at all scales not stabilized by turbulent forces, viscous forces, other forces, or diffusion. The Jeans acoustic scale L_J is the size for which pressure can equilibrate acoustically without temperature change in an ideal gas undergoing self gravitational collapse or void formation, smoothing away all pressure forces and all pressure resistance to self gravity. The Jeans hydrostatic scale L_{JHS} is the size of a fluid blob for which irreversibilities such as frictional forces or thermonuclear heating have achieved a hydrostatic equilibrium between pressure and gravitation. L_{JHS} is generically much smaller than L_J and has no physical significance until gravitational condensation has actually occurred and a hydrostatic equilibrium has been achieved.

When gas condenses on a non-acoustic density maximum due to self gravity a variety of results are possible. If the amount is large a turbulent maelstrom, superstar and black hole will appear. If the amount is small a gas planet, brown dwarf or star will form in hydrostatic equilibrium as the gravitational potential energy is converted to heat by turbulent friction and radiated. The pressure force $F_P \approx p \times L^2$ matches the gravitational force of the star or gas planet at $F_G \approx \rho^2 GL^4$ at the hydrostatic Jeans scale L_{JHS} . Pressure p is determined by a complex mass-momentum-energy balance of the fluid flow and ambient conditions. A gas with uniform density is absolutely unstable to self gravitational structure formation on

non-acoustic density perturbations at scales larger and smaller than L_J and is unstable to acoustical density fluctuations on scales larger than L_J (Gibson 1996). Contrary to the common misconception, pressure and temperature cannot prevent structure formation on scales larger or smaller than L_J .

Density fluctuations in fluids are not barotropic as assumed by Jeans 1902 except rarely in small regions for short times near powerful sound sources. Density fluctuations that triggered the first gravitational structures in the primordial fluids of interest were likely non-acoustic (non-barotropic) density variations from turbulent mixing of temperature or chemical species concentrations produced by the big bang (Gibson 2001) as shown by turbulent signatures (Bershanskii and Sreenivasan 2002) in the cosmic microwave background temperature anisotropies. From Jeans' theory without Jeans' swindle, a gravitational condensation on an acoustical density maximum rapidly becomes a non-acoustical density maximum because the gravitationally accreted mass retains the (zero) momentum of the motionless ambient gas. The Jeans 1902 analysis was ill posed because it failed to include non-acoustic density variations as an initial condition.

Fluids with non-acoustic density fluctuations are continuously in a state of structure formation due to self gravity unless prevented by diffusion or fluid forces (Gibson 1996). Turbulence or viscous forces can dominate gravitational forces at small distances from a point of maximum or minimum density to prevent gravitational structure formation, but gravitational forces will dominate turbulent or viscous forces at larger distances to cause structures if the gas or plasma does not diffuse away faster than it can condense or rarify due to gravity. The erroneous concepts of pressure support and thermal support are artifacts of the erroneous Jeans criterion for gravitational instability. Pressure forces could not prevent gravitational structure formation in the plasma epoch because pressures equilibrate in time periods smaller than the gravitational free fall time $(\rho G)^{-1/2}$ on length scales smaller than the Jeans scale L_J , and L_J in the primordial plasma was larger than the Hubble scale of causal connection $L_J > L_H = ct$, where c is light speed and t is time. Therefore, if gravitational forces exceed viscous and turbulence forces in the plasma epoch at Schwarz scales L_{ST} and L_{SV} smaller than L_H (Table 1) then gravitational structures will develop, independent of the Jeans criterion. Only a very large diffusivity (D_B) could interfere with structure formation in the plasma. Diffusion prevents gravitational clumping of the non-baryonic dark matter (cold or hot) in the plasma epoch because $D_{NB} \gg D_B$ and $(L_{SD})_{NB} \gg L_H$.

Consider the gravitational response of a large body of uniform density gas to a sudden change at time $t = 0$ on scale $L \ll L_J$ of a rigid mass $M(t)$ at the center, either a cannonball or vacuum beach ball depending on whether $M(0)$ is positive or negative. Gravitational forces will cause all the surrounding gas to accelerate slowly toward or away from the central mass

perturbation. The radial velocity $v_r = -GM(t)tr^{-2}$ by integrating the radial gravitational acceleration and the central mass increases at a rate $dM(t)/dt = -v_r 4\pi r^2 \rho = 4\pi \rho GM(t)t$. Separating variables and integrating gives $M(t) = M(0)\exp(2\pi\rho Gt^2)$. Nothing much happens for time periods less than the gravitational free fall time $t_G = (\rho G)^{-1/2}$ except for a gradual build up or depletion of the gas near the center where the hydrostatic pressure changes are concentrated at the Jeans hydrostatic scale $L_{JHS} \ll L_J$. At $t = 0.43t_G$ the mass ratio $M(t)/M(0)$ for $r < L$ has increased by only a factor of 2.7, but goes from 534 at $t = t_G$ to 10^{11} at $t = 2t_G$ during the time it would take for an acoustic signal to reach a distance L_J . Pressure support and the Jeans 1902 criterion clearly fail in this exercise.

The diffusion velocity is D/L for diffusivity D at distance L and the gravitational velocity is $L(\rho G)^{1/2}$. The two velocities are equal at the diffusive Schwarz length scale

$$L_{SD} \equiv [D^2/\rho G]^{1/4}. \quad (2)$$

Weakly collisional particles such as the hypothetical cold-dark-matter (CDM) material cannot possibly form clumps, seeds, halos, or potential wells for baryonic matter collection because the CDM particles have large diffusivity and will disperse, consistent with observations (Sand et al. 2002). Diffusivity $D \approx V_p \times L_c$, where V_p is the particle speed and L_c is the collision distance. Because weakly collisional particles have large collision distances with large diffusive Schwarz lengths the non-baryonic dark matter (possibly neutrinos) is the last material to fragment by self gravity and not the first as assumed by CDM cosmologies. The first structures occur as proto-supercluster-voids in the baryonic plasma controlled by viscous and weak turbulence forces, independent of diffusivity ($D \approx \nu$). The CDM seeds postulated as the basis of CDMHCC never happened because $(L_{SD})_{NB} \gg ct$ in the plasma epoch. Because CDM seeds and halos never happened, hierarchical clustering of CDM halos to form galaxies and their clusters never happened.

Cold dark matter was invented to explain the observation that gravitational structure formed early in the universe that should not be there from the Jeans 1902 criterion that forbids structure in the baryonic plasma because $(L_J)_B > L_H$ during the plasma epoch (where sound speed approached light speed $V_S = c/\sqrt{3}$). In this CDM cosmology, non-baryonic particles with rest mass sufficient to be non-relativistic at their time of decoupling are considered “cold” dark matter, and are assumed to form permanent, cohesive clumps in virial equilibrium that can only interact with matter and other CDM clumps gravitationally. This assumption that CDM clumps are cohesive is questioned here as unnecessary and unrealistic. Numerical simulations of large numbers of such cohesive CDM clumps show a tendency for the clumps to clump further due to gravity to form “halos”, justifying the cold dark matter hierarchical clustering cosmology (CDMHCC) where the baryonic matter eventually falls into the gravitational potential wells of the CDM halos, cools off, and forms the observed

stars and structures. As we have seen, CDMHCC is not necessary since the Jeans criterion is incorrect and baryons can begin gravitational structure formation during the plasma epoch. Furthermore, CDMCC is not possible because the nearly collisionless non-baryonic matter would not clump or form massive halos as assumed but would diffuse away.

Clumps of collisionless or collisional CDM would either form black holes or thermalize in time periods of order the gravitational free fall time $(\rho G)^{-1/2}$ because the particles would gravitate to the center of the clump by core collapse where the density would exponentiate, causing double and triple gravitational interactions or particle collisions that would thermalize the velocity distribution and trigger diffusional evaporation. For collisional CDM, consider a spherical clump of perfectly cold CDM with mass M , density ρ , particle mass m and collision cross section σ . The clump collapses in time $(\rho G)^{-1/2}$ to density $\rho_c = (m/\sigma)^{3/2} M^{-1/2}$ where collisions begin and the velocity distribution thermalizes. Particles with velocities greater than the escape velocity $v \approx 2MG/r$ then diffuse away from the clump, where $r = (M/\rho)^{1/3}$ is the initial clump size. For typically considered CDM clumps of mass $\approx 10^{36}$ kg and CDM particles more massive than 10^{-24} kg (WIMPs with $\sigma \approx 10^{-42}$ m² small enough to escape detection) the density from the expression would require a collision scale smaller than the clump Schwarzschild radius so that such CDM clumps would collapse to form black holes. Less massive motionless CDM particles collapse to diffusive densities smaller than the black hole density, have collisions, thermalize, and diffuse away. From the outer halo radius size measured for galaxy cluster halos it is possible to estimate the non-baryonic dark matter particle mass to be of order 10^{-35} kg (10 eV) and the diffusivity to be $\approx 10^{-30}$ m² s⁻¹ (Gibson 2000). Thus, CDM clumps are neither necessary nor physically possible, and are ruled out by observations (Sand et al. 2002). It is recommended that the CDMHCC scenario for structure formation and cosmology be abandoned.

The baryonic matter is subject to large viscous forces, especially in the hot primordial plasma and gas states existing when most gravitational structures first formed (Gibson 2000). The viscous forces per unit volume $\rho\nu\gamma L^2$ dominate gravitational forces $\rho^2 GL^4$ at small scales, where ν is the kinematic viscosity and γ is the rate of strain of the fluid. The forces match at the viscous Schwarz length

$$L_{SV} \equiv (\nu\gamma/\rho G)^{1/2}, \quad (3)$$

which is the smallest size for self gravitational condensation or void formation in such a flow. Turbulent forces may permit larger mass gravitational structures to develop; for example, in thermonuclear maelstroms at galaxy cores to form central black holes. Turbulent forces $\rho\varepsilon^{2/3}L^{8/3}$ match gravitational forces at the turbulent Schwarz scale

$$L_{ST} \equiv \varepsilon^{1/2}/(\rho G)^{3/4}, \quad (4)$$

where ε is the viscous dissipation rate of the turbulence. Because in the primordial plasma the viscosity and diffusivity are identical and the rate-of-strain γ is larger than the free-fall frequency $(\rho G)^{1/2}$, the viscous and turbulent Schwarz scales L_{SV} and L_{ST} will be larger than the diffusive Schwarz scale L_{SD} , from (2), (3) and (4).

The criterion for structure formation in the plasma epoch is that both L_{SV} and L_{ST} become less than the horizon scale $L_H = ct$. Reynolds numbers in the plasma epoch were near critical, with $L_{SV} \approx L_{ST}$. From $L_{SV} < ct$, gravitational structures first formed when ν first decreased to values less than radiation dominated values c^2t at time $t \approx 10^{12}$ seconds (Gibson 1996), well before 10^{13} seconds which is the time of plasma to gas transition (300,000 years). Because the expansion of the universe inhibited condensation but enhanced void formation in the weakly turbulent plasma, the first structures were proto-supercluster-voids in the baryonic plasma. At 10^{12} s

$$(L_{SD})_{NB} \gg L_{SV} \approx L_{ST} \approx 5 \times L_K \approx L_H = 3 \times 10^{20} \text{m} \gg L_{SD}, \quad (5)$$

where $(L_{SD})_{NB}$ refers to the non-baryonic component and L_{SV} , L_{ST} , L_K , and L_{SD} scales refer to the baryonic (plasma) component.

As proto-supercluster mass plasma fragments formed, the voids filled with non-baryonic matter by diffusion, thus inhibiting further structure formation by decreasing the gravitational driving force. The baryonic mass density $\rho \approx 2 \times 10^{-17} \text{ kg/m}^3$ and rate of strain $\gamma \approx 10^{-12} \text{ s}^{-1}$ were preserved as hydrodynamic fossils within the proto-supercluster fragments and within proto-cluster and proto-galaxy objects resulting from subsequent fragmentation as the photon viscosity and L_{SV} decreased prior to the plasma-gas transition and photon decoupling (Gibson 2000). As shown in Eq. 5, the Kolmogorov scale $L_K \equiv [\nu^3/\varepsilon]^{1/4}$ and the viscous and turbulent Schwarz scales at the time of first structure matched the horizon scale $L_H \equiv ct \approx 3 \times 10^{20} \text{ m}$, freezing in the density, strain-rate, and spin magnitudes and directions of the subsequent proto-cluster and proto-galaxy fragments of proto-superclusters. Remnants of the strain-rate and spin magnitudes and directions of the weak turbulence at the time of first structure formation are forms of fossil vorticity turbulence (Gibson 1999).

The quiet condition of the primordial gas is revealed by measurements of temperature fluctuations of the cosmic microwave background radiation that show an average $\delta T/T \approx 10^{-5}$ much too small for any turbulence to have existed at that time of plasma-gas transition (10^{13} s). Turbulent plasma motions are strongly damped by buoyancy forces at horizon scales after the first gravitational fragmentation time 10^{12} s. Viscous forces in the plasma are inadequate to explain the lack of primordial turbulence ($\nu \geq 10^{30} \text{ m}^2 \text{ s}^{-1}$ is required but, after 10^{12} s, $\nu \leq 4 \times 10^{26}$, Gibson 2000). The observed lack of plasma turbulence proves that large scale buoyancy forces, and therefore self gravitational structure formation, must have begun in the plasma epoch.

The gas temperature, density, viscosity, and rate of strain are all precisely known at transition, so the gas viscous Schwarz mass $L_{SV}^3 \rho$ is easily calculated to be about 10^{24} kg, the mass of a small planet, or about $10^{-6} M_{\odot}$, with uncertainty about a factor of ten. From HGT, soon after the cooling primordial plasma turned to gas at 10^{13} s (300,000 yr), the entire baryonic universe condensed to a fog of planetary-mass primordial-fog-particles (PFPs) that preventing collapse at the Jeans mass. These gas-cloud objects gradually cooled, formed H-He rain, and eventually froze solid to become the baryonic dark matter and the basic material of construction for stars and everything else, about 30×10^6 rogue planets per star.

The Jeans mass $L_J^3 \rho$ of the primordial gas at transition was about $10^6 M_{\odot}$ with about a factor of ten uncertainty, the mass of a globular-star-cluster (GC). Proto-galaxies fragmented at the PFP scale but also at this proto-globular-star-cluster PGC scale L_J , although not for the reason given by the Jeans 1902 theory. Density fluctuations in the gaseous proto-galaxies were absolutely unstable to void formation at all scales larger than the viscous Schwarz scale L_{SV} . Pressure can only remain in equilibrium with density without temperature changes in a gravitationally expanding void on scales smaller than the Jeans scale. From the second law of thermodynamics, rarefaction wave speeds that develop as density minima expand due to gravity to form voids are limited to speeds less than the sonic velocity. Cooling could therefore occur and be compensated by radiation in the otherwise isothermal primordial gas when the expanding voids approached the Jeans scale. Gravitational fragmentations of proto-galaxies were then accelerated by radiative heat transfer to these cooler regions, resulting in fragmentation at the Jeans scale and isolation of proto-globular-star-clusters (PGCs) with the primordial-gas-Jeans-mass.

These 10^{36} kg PGC objects were not able to collapse from their own self gravity because of their internal fragmentation at the viscous Schwarz scale to form 10^{24} kg PFPs. The fact that globular star clusters have precisely the same density and primordial-gas-Jeans-mass from galaxy to galaxy proves they were all formed simultaneously soon after the time of the plasma to gas transition 10^{13} s. The gas has never been so uniform since, and no mechanism exists to recover such a high density, let alone such a high uniform density, as the fossil turbulent density value $\rho \approx 2 \times 10^{-17}$ kg/m³. Young globular cluster formation in BDM halos in the Tadpole, Mice, and Antennae galaxy mergers (Gibson & Schild 2003a) show that dark PGC clusters of PFPs are remarkably stable structures, persisting without disruption or star formation for more than ten billion years.

2.2. Observational evidence for PGCs and PFPs

Searches for point mass objects as the dark matter by looking for microlensing of stars in the bulge and the Magellanic clouds have detected only about 20% of the expected amount, leading to claims by the MACHO/OGLE/EROS consortia that this form of dark matter has been observationally excluded (Alcock et al. 1998). These studies have assumed a uniform rather than clumped distribution for the “massive compact halo objects” (MACHOs) and used sampling frequencies appropriate for stellar rather than small planetary mass objects. Furthermore, since the PFPs within PGC clumps must accretionally cascade over a million-fold mass range to produce JPPs and stars their statistical distribution becomes an intermittent lognormal that profoundly affects the sampling strategy and microlensing data interpretation and makes the exclusion of PFP mass objects as the baryonic dark matter (BDM) of the Galaxy premature (Gibson & Schild 1999). Recent OGLE campaigns focusing on planetary mass to brown dwarf mass objects have revealed 121 transiting and orbiting candidates, some with orbits less than one day indicating the end of the PFP accretional cascade predicted by HGT as the mechanism of star formation (Udalski et al. 2003).

Evidence that planetary mass objects dominate the BDM in galaxies has been gradually accumulating and has been reviewed (Gibson & Schild 2003b). Cometary knot candidates for PFPs and JPPs appear whenever hot events like white dwarfs, novae, plasma jets, Herbig-Haro objects, and supernovae happen, consistent with the prediction of HGT that the knots reveal Jovian planets that comprise the BDM, as we see for the planetary nebulae in the present paper. However, the most convincing evidence for our hypothesis, because it averages the dark matter over much larger volumes of space, is provided by one of the most technically challenging areas in astronomy; that is, quasar microlensing (Schild 1996). Several years and many dedicated observers were required to confirm the Schild measured time delay of the Q0957 lensed quasar images so that the twinkling of the subtracted light curves could be confirmed and the frequency of twinkling interpreted as evidence that the dominant point mass objects of the lensing galaxy were of small planetary mass. By using multiple observatories around the Earth it has now been possible to accurately establish the Q0957 time delay at 417.09 ± 0.07 days (Colley et al. 2002, 2003). With this unprecedented accuracy a statistically significant microlensing event of only 12 hours has now been detected (Colley & Schild. 2003) indicating a PFP with Moon-mass only 7.4×10^{22} kg. An additional microlensing system has been observed (Schechter et al. 2003) and confirmed, and its time delay measured (Ofek and Maoz 2003). To attribute the microlensing to stars rather than planets required Schechter et al. to propose relativistic knots in the quasar. An additional four lensed quasar systems with measured time delays show monthly period microlensing that support dominant BDM objects in the lens with planetary mass (Burdud et al. 2000, 2002; Hjorth et al. 2002).

Flux anomalies in four-image gravitational lenses have been interpreted as evidence for the dark matter substructure predicted by CDM halo models (Dalal and Kochanek 2002), but the anomalies can also be taken as evidence for concentrations of baryonic dark matter such as PGCs, especially when the images are found to twinkle with frequencies consistent with the existence of planetary mass objects. Further evidence that the planetary objects causing the high frequency twinkling are clumped as PGCs is provided by evidence that the HE1104 system (Schechter et al. 2003) has a damped Lyman alpha lensing system (DLA \equiv neutral hydrogen column density larger than $10^{24.3} \text{ m}^{-2}$), which is therefore a PGC candidate from the evidence of gas and planets. Active searches are underway for lensed DLAs with planetary frequency twinkling that can add to this evidence of PGCs. Perhaps the most remarkable evidence suggesting galaxy inner halos consist mostly of baryonic PGC-PFP clumps are the recent HST/ACS images of aligned rows of YGCs precisely tracking the merging galaxy in the Tadpole system (Gibson & Schild 2003a).

Numerous YGCs are also seen in the fragmenting galaxy cluster Stephan’s Quintet (Gibson & Schild 2003c). The mysterious red shifts of the dense-cluster support the HGT model of sticky beginnings of the cluster in the plasma epoch, where viscous forces of the baryonic dark matter halo of the cluster have inhibited the final breakup due to the expansion of the universe to about 200 million years ago and reduced the transverse velocities of the galaxies to small values so that they appear aligned in a thin pencil by perspective. Close alignments of QSOs with bright galaxies (suggesting intrinsic red shifts) have been noted for many years (Hoyle et al. 2000) that can more easily be explained by HGT without requiring new physics.

2.3. Planetary Nebula formation

2.3.1. *The standard model*

According to the standard model of planetary nebula formation, an ordinary star like the sun eventually burns most of its hydrogen and helium to form a hot, dense, carbon core. In its last stages the remaining H-He fuel forms a progressively less dense atmosphere that expands from $\approx 10^9 \text{ m}$ to 10^{11} m or more to form a cool 3000 K red giant cocoon around the carbon center. This neutral atmosphere of the red giant with density $\approx 10^{-17} \text{ kg m}^{-3}$ is eventually expelled by dynamical and photon pressures when the hot $\approx 10^5 \text{ K}$, dense $\approx 10^{10} \text{ kg m}^{-3}$, carbon core is exposed as a white dwarf star with no source of fuel unless accompanied by a donor companion. The density of this 10^{16} kg atmosphere at a distance of $3 \times 10^{15} \text{ m}$ corresponding to the inner Helix radius is only $3.7 \times 10^{-31} \text{ kg m}^{-3}$, which is 2.7×10^{16} times smaller than the observed density of the cometary knots. Larger stars up to $5M_{\odot}$ form

white dwarfs and have complex histories with super-wind Asymptotic Giant Branch (AGB) periods where many solar masses are expelled into the ISM (Busso et al. 1999). At most this could bring the density within a factor of 10^3 of that observed in the knots. It has been proposed in versions of the standard model that either the cometary knots are produced by shock wave instabilities and are somehow ejected by the central stars (Vishniac 1994) or the photo-ionized inner surface of the denser ejected atmosphere forms Rayleigh-Taylor instabilities so that fingers like dripping paint break into the cometary globules and radial wakes observed (Capriotti 1973).

Several problems exist for this standard model. The huge masses of the observed planetary nebulae H-He gasses are much larger and richer in other species and dust than one would expect to be expelled as stellar winds or cometary bullets during any reasonable model of star evolution, where most of the star’s H-He fuel should be converted by thermonuclear fusion to carbon in the core before the star dies. Instead, more than a solar mass of gas and dust is found in the nebular ring of Helix, with a dusty H-He-O-N-CO composition matching that of the interstellar medium rather than winds from the hydrogen-depleted atmosphere of a carbon star. The cometary globules are too massive and too dense to match the Rayleigh-Taylor instability model. The maximum density increase due to a shock wave is a factor of six: less from Rayleigh-Taylor instabilities. Turbulence dispersion of nonlinear thin shell instabilities (Vishniac 1994) should decrease or prevent shock induced or gravitational increases in density. The measured density of the Helix cometary globule atmospheres is $\approx 10^{-14}$ kg m $^{-3}$ and their masses are a few times 10^{25} kg. No mechanism is known by which such massive dense objects can form or exist near the central star, or be ejected without disruption to the distances where they are observed.

2.3.2. *The HGT model*

According to HGT, stars are formed by accretion of PFP planets and the larger Jovian PFP planets (JPPs) and red dwarf stars accreted from PFPs within the PGC interstellar medium. The accretion mechanism is likely to be binary, where two PFPs or Jovians experience a near collision so that frictional heating of their atmospheres produces evaporation of the solid planets and an increase in the amount of gas in their atmospheres. This results in a non-linear “frictional hardening” of the binary planets until the two objects merge, and explains why “3 out of every 2 stars is a binary” (Cecilia Payne-Gaposchkin). Heating from the merger will result in a large atmosphere for the double-mass PFP that will increase its cross section for capture of more PFPs. The large atmosphere also increases the friction with randomly encountered ambient PFP atmospheres that will slow the relative motion of

the objects and increase the time between their collisions and mergers. Radiation to outer space will cause the PFP atmospheres to cool and eventually rain out and freeze if no further captures occur, leading to a new state of metastable equilibrium with the ambient gas. To reach Jupiter mass, $10^{-6}M_{\odot}$ mass PFPs and their growing sons and daughters must pair 10 times ($2^{10} \approx 10^3$). To reach stellar mass, 20 PFP binary pairings are required ($2^{20} \approx 10^6$). Because of the binary nature of PFP structure formation, it seems likely that double stars will result, as observed, and that the stars will have large numbers of large gassy planets, as observed. Rocky planets like the Earth in this scenario are simply the rocky cores of Jupiters that have processed the dust accumulated gravitationally from supernova remnants in their cores and in the cores of the thousands of PFPs that they have accreted to achieve their masses. Without PFPs, the existence of rocks is a mystery.

Large gas planets from PFP accretion cascades may form gently over long periods, with ample time at every stage for their atmospheres to readjust with ambient conditions and return to metastable states of random motion. These are probably the conditions under which the old globular star clusters (OGCs) in the halo of the Milky Way Galaxy formed their small long-lived stars. However, if the PFP accretional cascade is forced by radiation or tidal forces from passing stars or ambient supernovae, a more rapid cascade will occur where the PFP atmospheres become large and the relative motions become highly turbulent. The turbulence will mix the PFPs and their large planet descendants and inhibit large average density increases or decreases. In this case another instability becomes possible; that is, if the turbulence weakens the creation of large central density structures, but enhances accretion to form large planets and brown dwarfs, the increased densities can become so rapid that buoyancy forces may develop from the density gradients. This will suddenly damp the turbulence at the Schwarz turbulence scale L_{ST} (see Table 1) to produce fossil turbulence (Gibson 1999) in a volume containing many solar masses of gas, PFPs and JPPs.

Turbulence fossilization due to buoyancy creates a gravitational collapse to the center of the resulting non-turbulent gas and PFPs from the sudden lack of turbulence resistance. A fossil turbulence hole in the ISM will be left with size determined by the turbulence levels existing at the beginning of fossilization. The accretion of the planets and gas within the hole will be accelerated by the rapidly increasing density. The total mass of the stars produced will be the size of the hole times the ISM density. If the mass is many solar masses then the superstars formed will soon explode as supernovae, triggering a sequence of ambient PFP evaporations, accretional cascades, and a starburst that may consume the entire dark PGC and PFPs to produce a million stars and a young globular cluster (YGC) or a super-star cluster (Tran et al. 2003). Numerous YCCs are triggered into formation by galaxy mergers, such as the merging of two galaxies and some fragments revealing a 130 kpc (4×10^{21} m) radius baryonic dark matter halo in the VV29abcdef Tadpole complex imaged by HST/ACS

immediately after installation of the ACS camera. Figure 1 shows a dark dwarf galaxy, revealed in the baryonic dark matter halo of the central Tadpole galaxy VV29a by a dense trail of YGCs pointing precisely to the spiral star wake produced as the dwarf blue galaxy VV29c and companions VV29def merged with VV29a (Gibson & Schild 2003a).

Planetary nebula form when one of the smaller stars formed by PFP accretion uses up all its H-He fuel to form a dense carbon core with temperature less than 8×10^8 K, the star forms a white dwarf and the high temperatures and radiation pressure of the white dwarf expel the atmosphere of the final asymptotic giant branch red giant star (eg: Betelgeuse). Red giant stars have envelope diameters $\approx 10^{12}$ m and atmospheric densities $\approx 10^{-17}$ kg m $^{-3}$ with a 6×10^6 m diameter $\rho \approx 10^{10}$ kg m $^{-3}$ carbon star core (Chaisson & McMillan 2001), so the total mass expelled is only $\approx 10^{16}$ kg, or $\approx 10^{-8}M_{\odot}$, much less than the gas mass values $(3 - 1) \times M_{\odot}$ observed in planetary nebulae. Without HGT, this much gas is mysterious.

Because the white dwarf is likely to have a companion star (Guerrero et al. 2001), it is likely that the companion will donate mass to the white dwarf. The white dwarf has small size and high density, and is likely to spin rapidly with a strong magnetic field near its spin axis. The spinning magnetic field lines at the white dwarf poles capture the incoming plasma to produce powerful plasma jets perpendicular to the plane of rotation of the two stars. The accretion disk of the white dwarf may shield some of its radiation and broadly beam its radiation. When the plasma jet encounters a frozen PFP or Jupiter at the edge of the star accretion hole it increases the evaporation rate of the frozen gas planet and forms a cometary globule with an outward radial wake and inward ionization front, as observed.

3. Observations

Figure 2 shows a mosaic of nine HST/ACS images from the F658N filter (H $_{\alpha}$ and N II) that enhances the ionized cometary globules and their hydrogen tails. See <http://archive.stsci.edu/hst/helix/images.html>. A sphere with radius 3×10^{15} m is shown corresponding to the volume of primordial-fog-particles (PFPs) with mass density 2×10^{-17} kg m $^{-3}$ required to form two central solar mass stars by accretion of PFPs. The large comets closest to the central stars must be evaporating massive planets (Jupiters) to survive measured evaporation rates of $2 \times 10^{-8}M_{\odot}$ year $^{-1}$ (Meaburn et al. 1998) for the 20,000 year age of Helix. Massive planets are formed in the accretional cascade of PFPs to form stars according to HGT. The younger (2,000 year old) planetary nebula Spirograph (IC 418) shown below shows shock wave patterns from the supersonic stellar winds but no cometary PFP candidates within its fossil turbulence accretion sphere. The extended spherical nebular shell for Helix contains $\approx 20M_{\odot}$ of dark PFPs, from which $1.5 \times M_{\odot}$ has been evaporated

as gas and dust (Speck et al. 2002). Evidence for bipolar beamed radiation is shown by the brighter regions of the nebula in Fig. 2 at angles 10 and 4 o'clock, and by the light to dark transition after 11:30 suggesting the bipolar beam is rotating slowly clockwise. Note that the tails of the comets are long ($\approx 10^{15}$ m) before 11:30 and short or nonexistent afterward. Rayleigh-Taylor instability as a mechanism to produce the globules (Capriotti 1973) gives densities much too low. The beam appears to have started rotation at about 1 o'clock with deep penetration of the radiation on both sides, revolved once, and is observed with its bright edge at 11:30 having completed less than two revolutions to form the Helix spiral.

Figure 3 shows a Hubble Space Telescope Helix WFPC2 1996 image to the northeast in Helix where the closest comets to the center are found (O'Dell & Handron 1996). The large cometary globules shown have size about 10^{13} m and measured atmospheric mass 3×10^{25} kg, with spacing $\approx 10^{14}$ m, as expected for gas planets with some multiple of this mass in a relic concentration corresponding to the primordial plasma density $(3 - 1) \times 10^{-17}$ kg m $^{-3}$ at the time of first structure 30,000 years after the big bang. Most of these largest cometary globules probably have larger mass planets than PFPs at their cores to have survived the 20,000 year lifetime of the Helix planetary nebula with measured mass loss rates of order $10^{-8} M_{\odot}$ year $^{-1}$ (Meaburn et al. 1998). These are termed Jovian PFP planets (JPPs). The spacing of the cometary knots becomes closer for distances farther from the central stars, consistent with these objects having PFPs or small JPPs at their cores.

Figure 4 shows an example from the new ACS/WFPC composite images from the northern region of Helix confirming the uniform density of the cometary globules throughout the nebula, and presumably reflecting the ambient dark frozen PFPs and JPPs in the surrounding ISM. Larger JPPs are more likely to be found near the edge of the star accretional cavity, although the intervening PFPs at the edge would have evaporated.

Figure 5 shows the Eskimo planetary nebula, which is about twice the distance as Helix but is still close enough for the numerous cometary globules to be resolved. The PNe is smaller than Helix and has a central shocked region with no comets like the young Spirograph nebula shown at the bottom of Fig. 2. Gas planets with primordial plasma densities appear to be a generic feature of the ISM of this region of the Galaxy disk within a kpc of earth where PNe are resolved clearly by HST cameras.

Figure 6 shows details of the central region of the Dumbbell planetary nebula featuring numerous cometary globules and knots. The spacing of the objects is consistent with PFP and JPP planets with average mass density thousands of times the average for the Galaxy dominating the mass and species content of the ISM, and close to the primordial baryonic density of the time of first structure in the plasma epoch 30,000 years after the big bang as predicted by HGT.

4. Conclusions

High resolution wide angle HST/ACS images confirm and extend the previous WFPC2 HST picture of the Helix planetary nebula (O’Dell & Handron 1996) showing thousands of mysterious, closely spaced cometary globules with atmospheric masses ($\approx 2 \times 10^{25}$ kg) larger than Earth-mass (6×10^{24} kg), comets larger than the solar system out to Pluto (10^{13} m), and globule atmospheric densities ($\approx 10^{-14}$ kg m⁻³) a thousand times greater than the atmosphere of the red giant star before its expulsion to form the planetary nebula. The standard model of planetary nebula formation (Capriotti 1973), where Rayleigh-Taylor instabilities of a denser outer shell are triggered by collision with a high speed inner shell to form the globules, cannot account for the globules and cannot account for the large observed density and mass of the nebular gas and globules. The idea that accretional shocks can trigger gravitational instabilities (Vishniac 1994) to achieve such densities neglects turbulence dispersion, and no mechanism exists to expel such objects from the central stars. Shocks are seen in younger PNe than Helix (Figures 2 and 5) but are not accompanied by any cometary globules.

We conclude that a better model for interpreting the observations is that provided by hydro-gravitational theory (HGT) where the brightest cometary globules are Jovian accretions of primordial-fog-particle (PFP) Mars-mass frozen H-He planets formed at the plasma to gas transition 300,000 years after the big bang (Gibson 1996), consistent with quasar microlensing observations showing the lens galaxy mass is dominated by rogue planets “likely to be the missing mass” (Schild 1996). From HGT and all observations, these planetary PFPs and JPPs dominate the mass and gasses of the Galaxy disk interstellar medium (ISM) and the inner halo mass of galaxies within a radius from the core of about 100 kpc. Proto-galaxies formed during the plasma epoch fragmented after transition to gas at primordial Jeans and Schwarz scales (Table 1) to form proto-globular-star-cluster (PGC) clouds of PFPs that comprise the baryonic dark matter of the ISM and the inner galaxy halo. From HST Helix images, the density of the Galaxy disk ISM is that of proto-superclusters formed 30,000 years after the big bang; that is, $\rho \approx 2 \times 10^{-17}$ kg/m³, preserved as a hydrodynamic fossil and revealed by the $(10 - 4) \times 10^{13}$ m separations of the PFP candidates (cometary globules) observed in Helix that imply this density.

HST images of other nearby planetary nebula support our interpretation. Cometary globules brought out of the dark by beamed radiation from a central white dwarf and companion star appears to be a generic feature of planetary nebulae, showing that the disk ISM is dominated by small frozen accreting planets with such small separations that the mass density is that of a PGC, which is $\approx 10^4$ larger than that of the Galaxy.

Most of the information in this paper would not be available without the heroic work and dedication of astronaut John Mace Grunsfeld whose amazing preparation and skills exhibited during the fourth space telescope repair mission made HST/ACS images possible.

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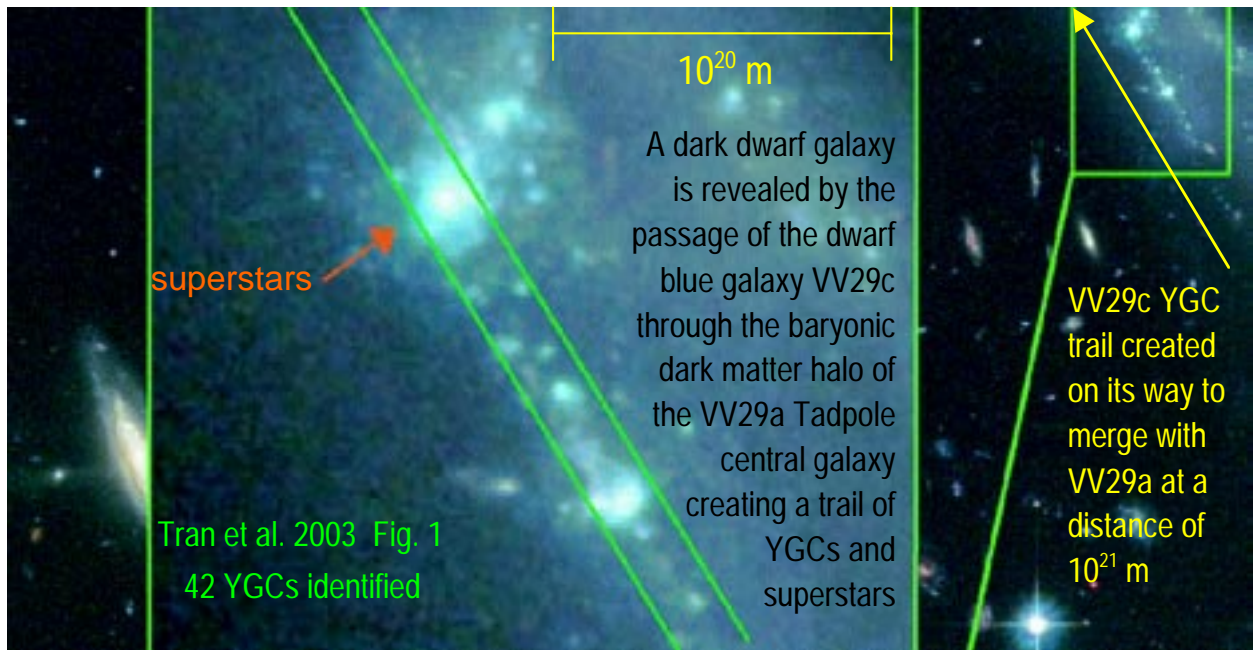


Fig. 1.— Trail of 42 YGCs in a dark dwarf galaxy examined spectroscopically by Tran et al. 2003 using the Keck telescope. The 1 " Echellette slit and a loose super-star-cluster (arrow) are shown at the left. Ages of the YGCs range from 3-10 Myr. The aligned YGC trail is extended by several more YGCs (arrow on right) and points precisely to the beginning, at 10^{21} m distance, of the spiral star wake of VV29c in its capture by VV29a. The baryonic dark matter halo of Tadpole is revealed by a looser trail of YGCs extending to a radius of 4×10^{21} m from VV29a, or 130 kpc (Gibson & Schild 2003a).

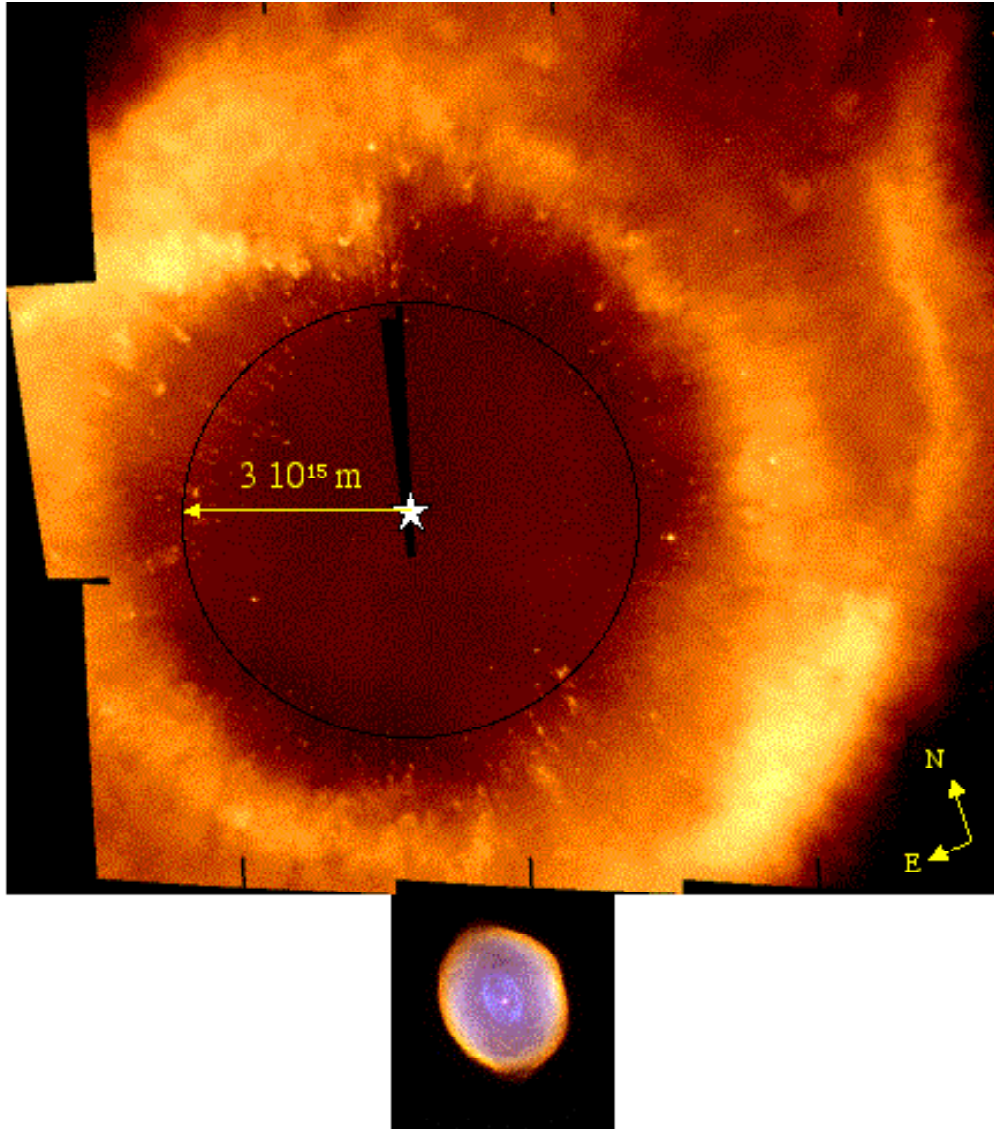


Fig. 2.— Helix Planetary Nebula HST/ACS/WFC F658N image mosaic. The sphere has radius 3×10^{15} m corresponding to the volume of primordial-fog-particles (PFPs) with mass density 3×10^{-17} kg m $^{-3}$ required to form two central stars by accretion. The comets within the sphere are from large gas planets (Jupiters, JPPs) that have survived evaporation rates of $2 \times 10^{-8} M_{\odot}$ /year (Meaburn et al. 1998) for the 20,000 year age of Helix. The younger planetary nebula Spirograph (IC 418) shown below with no PFPs is within its accretion sphere. The nebular sphere for Helix contains $\approx 20 M_{\odot}$ of dark PFP and JPP planets, from which $1.5 \times M_{\odot}$ has been evaporated as detectable gas and dust (Speck et al. 2002).

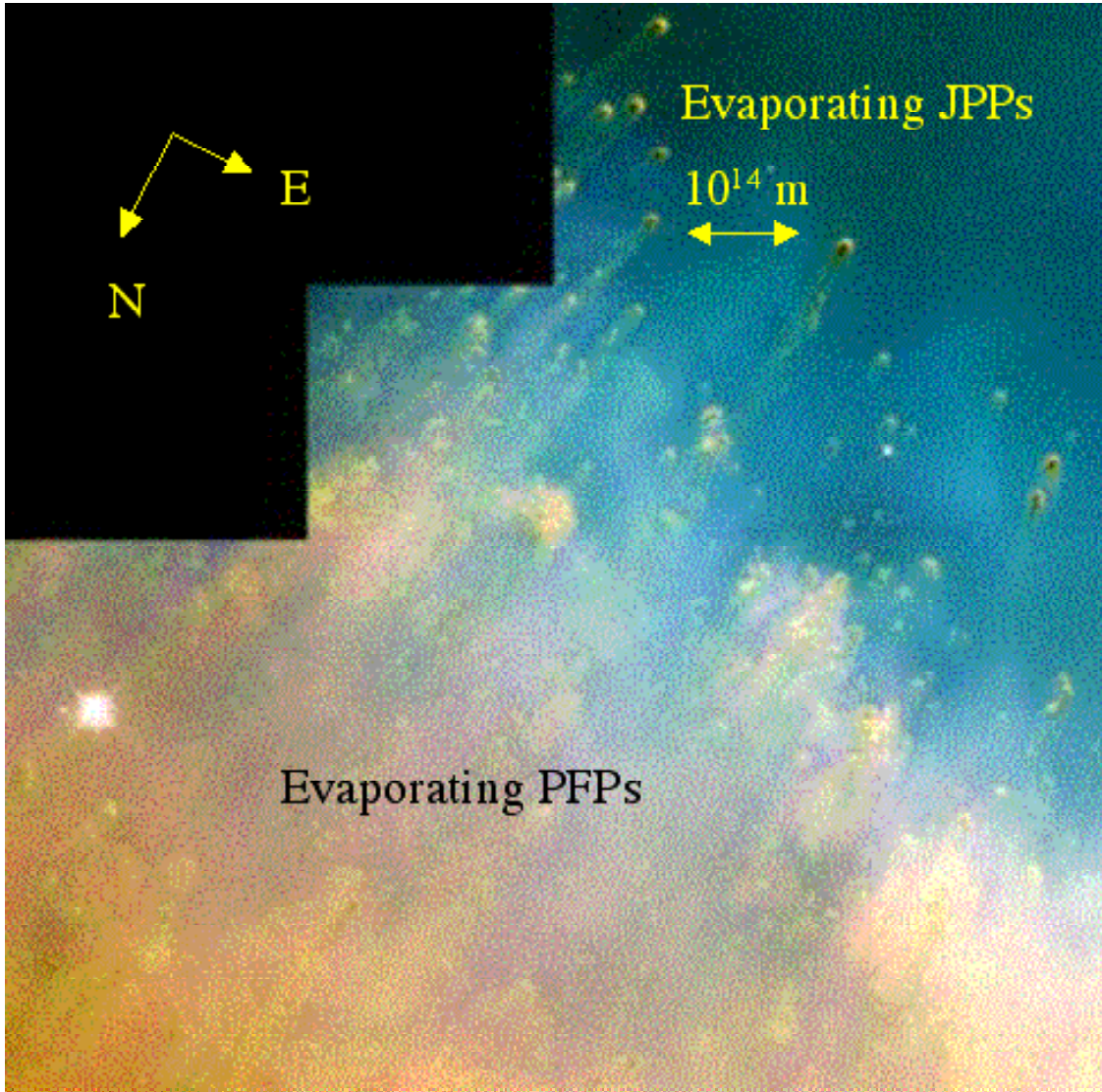


Fig. 3.— Helix Planetary Nebula HST/WFPC2 1996 image (O’Dell & Handron 1996) from the strongly illuminated northeast region of Helix containing the comets closest to the central stars ($\approx 2 \times 10^{15}$ m) with embedded ≥ 0.4 Jupiter mass planets. Cometary globules shown have size about 10^{13} m and mass 3×10^{25} kg just in their gas atmospheres, with spacing $\approx 10^{14}$ m, as expected for Jupiter mass JPPs with the primordial density 3×10^{-17} kg m⁻³. Closer spaced smaller objects without detectable wakes are the PFPs from which the JPPs formed by accretion.

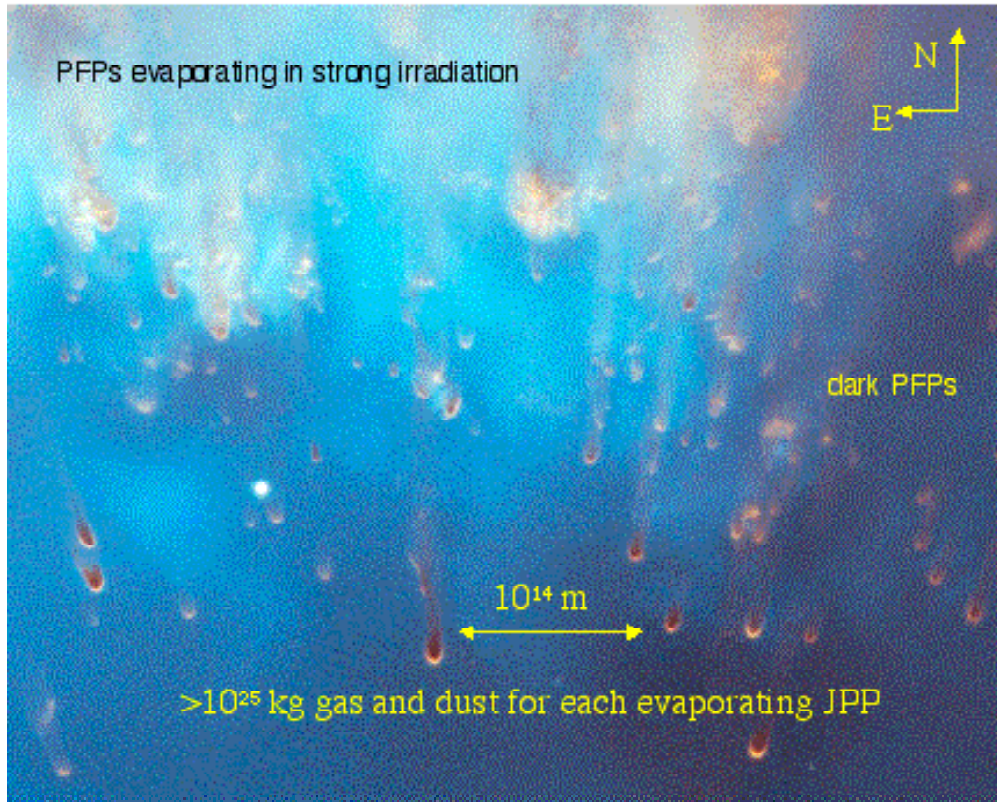


Fig. 4.— Detail of more closely spaced cometary globules to the north in Helix from the 2002 HST/ACS images at the dark to light transition marking the clockwise rotation of the beamed radiation from the central stars. The comets in the dark region to the right have shorter tails and appear smaller in diameter since they have recently had less intense radiation than the comets on the left. Two puffs of gas illuminated deep in the dark region show the gas has been reabsorbed on the PFPs by gravity during the several thousand years since their last time of strong irradiation. Small comets appear in the more strongly illuminated region to the left at the larger distances from the central stars even though these PFPs have been shielded by evaporated gas and dust. Such PFPs are invisible on the right in the dark region, showing they have reverted to their original dark matter state.

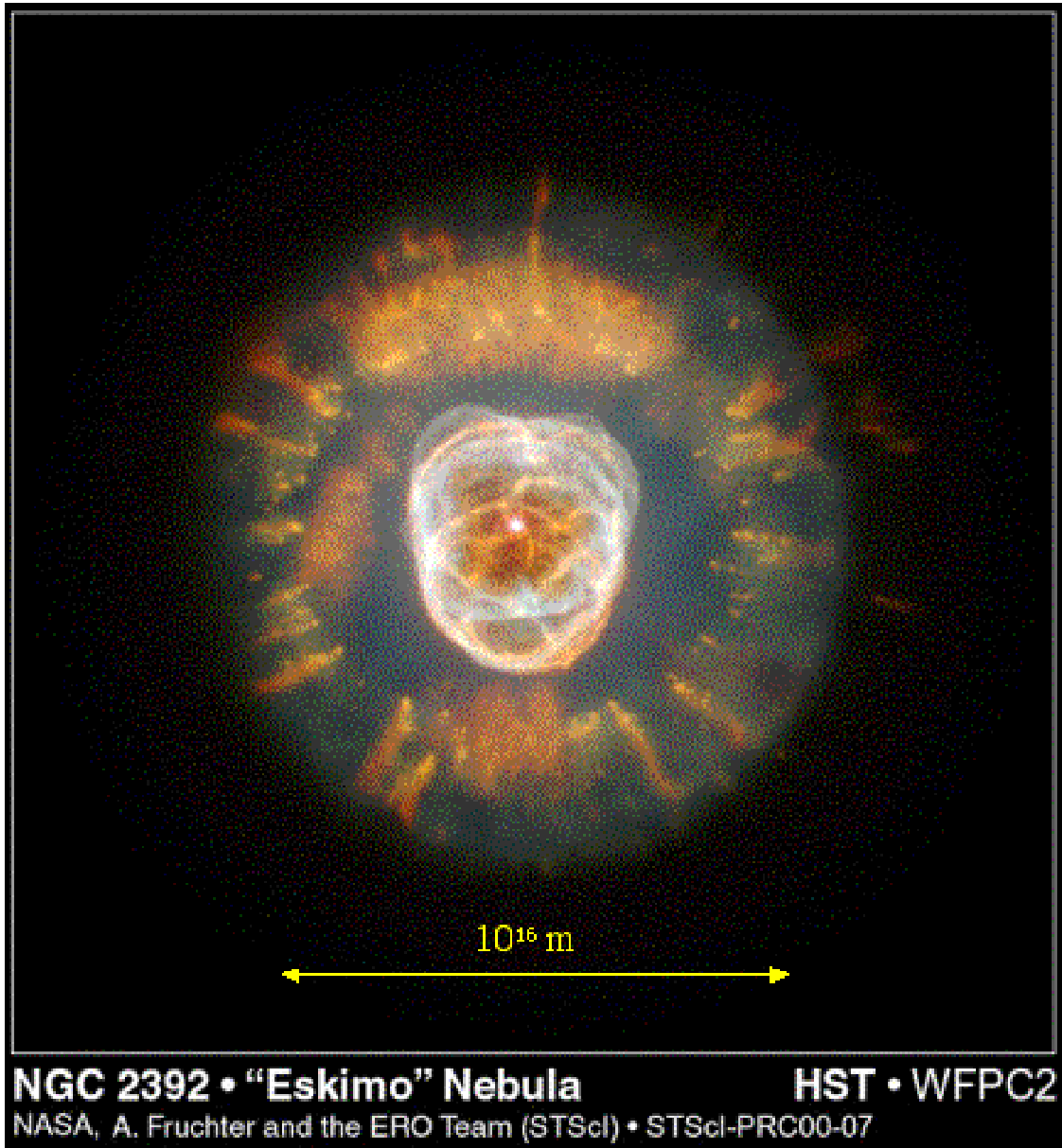


Fig. 5.— The Eskimo planetary nebula (NGC 2392) is about twice the distance from earth as Helix, but still shows numerous evaporating PFP and JPP candidates in its surrounding interstellar medium in the HST/WFPC images, with spacing consistent with the primordial plasma density. The nebula is smaller and younger than Helix, with a central shocked region like that of Spirograph in Fig. 2. Note the homogeneous distribution of comets in the gas nebula and the occasional comets appearing to the right outside the gas nebula, contrary to their formation by Rayleigh-Taylor fragmentation (Capriotti 1973).

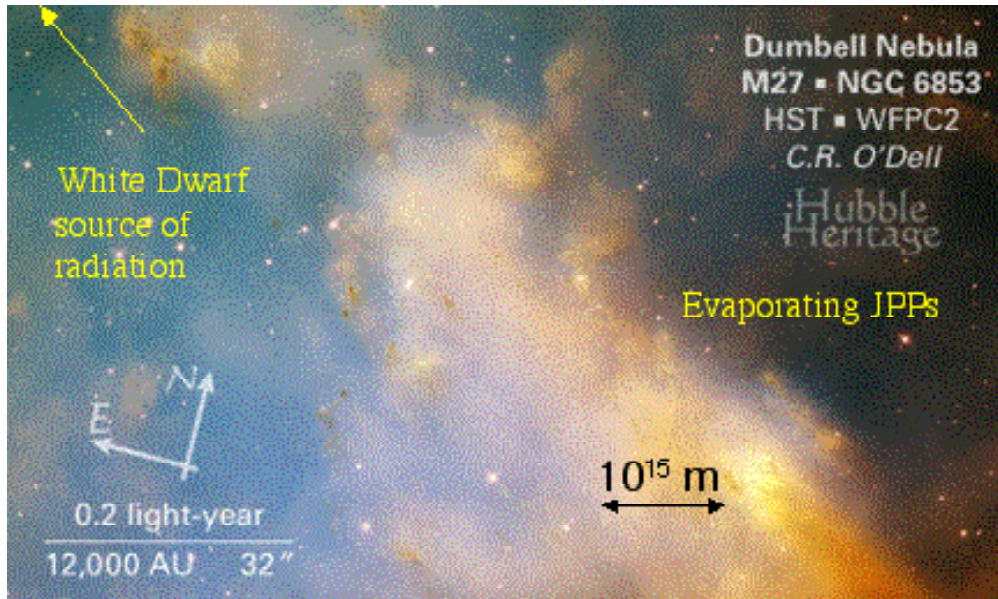


Fig. 6.— Closup image of the Dumbbell planetary nebula (M27, NGC 6853) shows numerous closely spaced, evaporating, irradiated PFP and JPP candidates in its central region. The PNe is at a distance $\approx 10^{19}$ m, with diameter $\approx 2 \times 10^{16}$ m. The white dwarf central star appears to have a companion from the double beamed radiation emitted. The lack an accretional hole may be the result of a different viewing angle (edgewise to the binary star plane) than the face-on views of Helix (Fig. 2) and Eskimo (Fig. 5).

Table 1. Length scales of self-gravitational structure formation

Length scale name	Symbol	Definition ^a	Physical significance ^b
Jeans Acoustic	L_J	$V_S/[\rho G]^{1/2}$	ideal gas pressure equilibration
Jeans Hydrostatic	L_{JHS}	$[p/\rho^2 G]^{1/2}$	hydrostatic pressure equilibration
Schwarz Diffusive	L_{SD}	$[D^2/\rho G]^{1/4}$	V_D balances V_G
Schwarz Viscous	L_{SV}	$[\gamma\nu/\rho G]^{1/2}$	viscous force balances gravitational force
Schwarz Turbulent	L_{ST}	$\varepsilon^{1/2}/[\rho G]^{3/4}$	turbulence force balances gravitational force
Kolmogorov Viscous	L_K	$[\nu^3/\varepsilon]^{1/4}$	turbulence force balances viscous force
Ozmidov Buoyancy	L_R	$[\varepsilon/N^3]^{1/2}$	buoyancy force balances turbulence force
Particle Collision	L_C	$m\sigma^{-1}\rho^{-1}$	distance between particle collisions
Hubble Horizon	L_H	ct	maximum scale of causal connection

^a V_S is sound speed, ρ is density, G is Newton’s constant, D is the diffusivity, $V_D \equiv D/L$ is the diffusive velocity at scale L , $V_G \equiv L[\rho G]^{1/2}$ is the gravitational velocity, γ is the strain rate, ν is the kinematic viscosity, ε is the viscous dissipation rate, $N \equiv [g\rho^{-1}\partial\rho/\partial z]^{1/2}$ is the stratification frequency, g is self-gravitational acceleration, z is in the opposite direction (up), m is the particle mass, σ is the collision cross section, c is light speed, t is the age of universe.

^bMagnetic and other forces (besides viscous and turbulence) are negligible for the epoch of primordial self-gravitational structure formation (Gibson 1996).

Table 2. Acronyms

Acronym	Meaning	Physical significance
BDM	Baryonic Dark Matter	PGC clumps of PFPs from HGT
CDM	Cold Dark Matter	questioned concept
CDMHCC	CDM HCC	questioned concepts
HCC	Hierarchical Clustering Cosmology	questioned concept
HCG	Hickson Compact Galaxy Cluster	Stephan’s Quintet (SQ=HGC 92)
HGT	Hydro-Gravitational Theory	corrects Jeans 1902
ISM	Inter-Stellar Medium	mostly PFPs and gas from PFPs
JPP	Jovian PFP Planet	planet formed by PFP accretion
NBDM	Non-Baryonic Dark Matter	includes and may be neutrinos
OGC	Old Globular star Cluster	PGC forms stars at $t \approx 10^6$ yr
PFP	Primordial Fog Particle	planet-mass protogalaxy fragment
PGC	Proto-Globular star Cluster	Jeans-mass protogalaxy fragment
SSC	Super-Star Cluster	a cluster of YGCs
YGC	Young Globular star Cluster	PGC forms stars at $t \approx$ now