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Dwarf Galaxies: A Comprehensive Exploration

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ABSTRACT

The fact that dwarf galaxies exhibit such a wide range of behaviour, from inconspicuous low surface brightness objects to the high surface brightness blue compact objects, is one of their most striking characteristics. Compared to typical spirals, their attributes have a much wider distribution. Small systems can readily undergo a fluctuation strong enough to entirely cease the propagation of star formation, according to the stochastic self-propagating star formation model (SSPSF). The likelihood of seeing a strong enough fluctuation to stop star formation will rise as the system's size decreases since the fluctuations encountered will vary inversely with system size.Small, low-mass galaxies known as dwarfs have a major impact on how we comprehend galaxy creation and development.

Keywords: Dwarf galaxies, Chemistry in dwarf galaxies, Globular clusters and dwarf galaxies, Chemical signatures in dwarf galaxies

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INTRODUCTION

Dwarf galaxies offer opportunities for monitoring our "cosmological backyard"—the Local Group and its vicinity—and making deductions about the activities in the early cosmos. An overview of the state-of-the-art in dwarf-galaxy cosmology is provided in this special issue of the open-access journal Advances in Astronomy.In comparison to the larger spiral and elliptical galaxies, which are more often viewed, our understanding of irregular dwarf galaxies is still in a more preliminary stage. This is due to two factors. The first is that because dwarfs have not been studied as extensively as their larger siblings, there is a dearth of crucial information needed to comprehend their characteristics. Second, it is unclear whether a coherent class of things definable by that name even exists given the enormous diversity of dwarf-related traits seen.

The Local Group (LG) appears to the rest of the universe as a typical cluster of dwarf galaxies that is dominated by two enormous spiral galaxies. But the Local Group holds a special significance for astronomers who are based on Earth and are interested in galaxy evolution. A particularly well-researched and statistically valuable sample of low-luminosity galaxies is provided by the dwarfs of the Local Group. In fact, the Local Group contains almost all of the currently known dwarfs that are less bright than MV 11.0 [1].The majority of galaxies in the universe today are dwarf galaxies [2], and they were very certainly much more common in earlier epochs [3].

Dwarf galaxies, previously considered to be a small number of 'boring' Milky Way satellites, are now acknowledged to be the largest and, arguably, most intriguing population of galaxies in the Universe thanks to impressive technological advancements in observational facilities. Further confirming the unexpected and complex central role of dwarfs in our investigation of the physics of star formation, stellar feedback, gas dynamics, tidal/ram pressure stripping, dark matter, and cosmic reionization, to name a few, are increasingly high-resolution simulations that carefully incorporate baryonic physics.

Globular clusters and dwarf galaxies may serve as excellent windows into the early stages of galaxy formation due to their simplicity and great antiquity. The contrasts between the two sorts of systems have, in some ways, started to become less clear in light of recent findings of local dwarfs. Globular clusters are regions of'sedate' (low efficiency) star formation, possibly independent of significant contributions from merging, while dwarf galaxies represent regions of much more'sedate' (low efficiency) star formation. Globular clusters are the product of 'intense' (what is often referred to as 'efficient') star formation processes.

Recent investigations of clusters show that low-luminosity dwarfs make up the vast bulk of all galaxies, despite the fact that the luminosity function for field galaxies is not well established at the faint end [4-6]. The three main kinds of dwarf galaxies—dwarf irregulars (dl), dwarf ellipticals (dE), and blue compact dwarfs (BCD)—as well as the less common compact dwarf ellipticals (cdE)—can be broadly divided into.

CHEMISTRY IN DWARF GALAXIES

The chemical evolution of dwarfs and clusters was a central theme of this workshop. Again, the distinctions between clusters and dwarfs are quite revealing. The most well-known example is perhaps the well-documented absence of amplification (relative to iron) of the a-elements of the stars in dwarf galaxies compared to metal-poor globular clusters [7].This boost is attributed by canonical chemical evolution models to Type II SNe at a population's peak star production epochs. The difference between dwarfs and clusters seems to indicate that while globular clusters formed from material that was already enriched in a-elements or self-enriched in these elements, dwarfs did not originate from such gas or produce much additional a-enriched gas that could have contaminated subsequent generations.

When we look at the mean abundances of globular clusters and dwarf galaxies as a function of baryonic content, we can see another significant chemical difference between them. It is generally known that there is no correlation between mean abundance and cluster luminosity among globular clusters.Dwarf galaxies, in contrast, demonstrate a substantial link between luminosity and mean chemical abundance, an important finding that was initially made some time ago [8].

Another aspect of the missing dwarf’s problem is the vast number of dwarf galaxies predicted by early cosmological models that are predicted to exist in voids but are not observed. Currently, it is believed that a deeper comprehension of the physics governing star formation would help to explain the differences between the observed and modelled dwarf galaxies in both environments.

GLOBULAR CLUSTERS AND DWARF GALAXIES

The fundamental differences between dwarf galaxies and globular clusters (GCs) are found in their structural characteristics [9]. While Dwarf Spheroidal (dSphs) are clearly separated, GCs and Ultra-Compact Dwarf (UCD) galaxies appear to define a distinct sequence in the mass versus central density plane, suggesting a similar formation mechanism. Although GCs and UCD galaxies appear to be a continuum, their two-body relaxation times differ greatly.Both GCs and UCD galaxies show little evidence of dark matter, which is consistent with expectations based on their size. Although they are relaxed objects, GCs have a decreased mass-to-light ratio, which is likely owing to dynamical evolution. In fact, because of energy equipartition and subsequent mass segregation, they selectively lose weak, low mass stars. While the classification of ambiguous objects, such as w Centauri, is not immediately clear, these differences are generally obvious. However, the existence of a continuum of features can help us better comprehend the processes that result in the production of GCs.

The presence of tidal tails is a glaring indication that both GCs and dwarf galaxies are known to shed stars to the general field. Two excellent examples are given by the GC Pal 5 [11] and the dSph galaxy Sagittarius [10], whose tail may be followed around the Milky Way and along a complete great circle. Two things follow from this occurrence of stellar loss: (i) a portion of the stars in the Galactic halo should have formed in these conditions; and (ii) the populations of GCs and dSphs that have been detected are the remnants of larger initial populations.

It is intriguing to contrast the chemical makeup of dSphs and GCs with that of field halo stars because they could contribute to the halo population. The preliminary findings for dSphs were very depressing [12]. Recently, however, [13] discovered that the metallicity distribution of the field stars with the lowest metal content broadly coincides with that of the stars in ultrafaint dSphs.

CHEMICAL SIGNATURES IN DWARF GALAXIES

Chemical signatures in dwarf galaxies are a term that refers to the analysis of particular elements abundance ratios to look into the development and evolution of dwarf galaxies, especially when compared to the variety of star populations in the Galaxy. We now find that the chemical evolution of dwarf galaxies is distinct from that of any other component of the Galaxy, casting doubt on the claim that dwarf galaxies like these built up the Galaxy. Detailed abundances of stars in dwarf galaxies can be utilised to reconstruct their chemical evolution. The period for significant merging and the potential for finding various star populations in the new ultra-dim dwarfs are potential answers to reconcile dwarf galaxy abundances with Galaxy formation models.

Dwarf galaxies are tiny, faint galaxies that are considerably less massive and bigger than other galaxies, such as the Milky Way. They are among the galaxy kinds that are most prevalent in the cosmos. Dwarf elliptical, dwarf irregular, and dwarf spheroidal galaxies are only a few of the several types of dwarf galaxies.

Similar to bigger elliptical galaxies but on a much smaller scale, dwarf elliptical galaxies are smooth and featureless in shape. They have little to no interstellar gas or dust and are primarily made up of older stars. These galaxies are frequently satellite galaxies of larger galaxies, and they typically sit on the periphery of galaxy clusters.

Dwarf irregular galaxies, on the other hand, have a more chaotic and irregular structure. They lack a distinct shape or symmetry and often exhibit ongoing star formation activity. Dwarf irregular galaxies tend to have a higher abundance of gas and dust, which fuels the formation of new stars. Examples of dwarf irregular galaxies include the Large and Small Magellanic Clouds, which are satellite galaxies of the Milky Way.

Dwarf spheroidal galaxies are faint, spheroidal-shaped galaxies that are typically found in the vicinity of larger galaxies, such as the Milky Way and the Andromeda Galaxy. They are low in gas and dust content and consist mainly of old stars. These galaxies have very little ongoing star formation activity and are often considered to be the remnants of ancient galaxies that were stripped of their gas and disrupted by gravitational interactions with larger galaxies.

Understanding the general structure and evolution of galaxies requires study of dwarf galaxies. They shed light on the beginnings of galaxy formation, the results of interactions with larger galaxies, and the part dark matter plays in determining the characteristics of galaxies. Additionally, the study of stellar populations, chemical abundances, and the mechanics of star formation in low-mass settings are carried out in dwarf galaxies.

THE COSMOLOGICAL SIGNIFICANCE OF THE LOWEST LUMINOSITY DWARF GALAXIES

A logical astronomer could question how the tiniest, least noticeable galaxies that have ever existed could be of such significance to astronomy. However, the UFDs are important objects to comprehend due to a number of factors that could have broad ramifications. First, the smallest dark matter halo yet discovered contains UFDs. The estimated virial masses of UFDs are 109 M [14], and the halo masses at the time the stars formed may have been 108 M [15, 16], even though only the mass at the very centre of the halo is currently quantifiable.

The known systems with the greatest dark matter dominance are UFDs. Due to their modest halo mass and little baryonic mass, UFDs are incredibly useful research tools for determining the properties of dark matter. The mass of the dark matter particle is constrained by counting how many such things there are in the Milky Way [17].

There are numerous dwarf galaxies known to occur in various environments, particularly close-by groups and clusters [18–24]. But there are underlying factors that continue to make the role of the Local Group particularly significant:

1. What connection, if any, exists between dwarf spheroidal/dwarf elliptical (dSph/dE) and dwarf irregular (dIrr) galaxies? Both types of low luminosity galaxies are mixed in the Local Group, which offers some unusual perspectives on this issue [25–27].

2. The low-luminosity dwarfs in the Local Group reflect a sample of galaxies that is still mostly made up of material that is still relatively young since low-luminosity dwarfs typically have low metal contents. The H II areas of dwarf galaxies are commonly used to determine their abundances, but only in the Local Group can we also reliably acquire abundances from resolved star populations. The wide luminosity range of LG dwarfs makes them ideal laboratories to investigate how other fundamental features, such as DM content, the characteristics of the interstellar medium (ISM), and star formation history, fluctuate with luminosity.

3. The known simplest galactic systems are those of dwarfs. LG dwarfs, however, are blatantly informing us that the phrase "simple" is relative. These galaxies' histories of star formation and chemical enrichment are intricate, diverse, and frequently initiated by unidentified causes. Since the Local Group galaxies are the only well-defined sample for which we can derive entire star-formation histories, HST is able to reach the main-sequence turnoff of the earliest stars in these galaxies [28].

4. One of the darkest single galaxies known may be a dwarf galaxy. Since they have previously imposed intriguing limits on the nature and distribution of DM and even whether the DM paradigm holds true for these systems [29, 30], they play a crucial role in tackling the dark-matter (DM) dilemma. We can only currently measure the interior kinematics of ultra-low surface brightness dwarfs in the Local Group.

5. Numerous interactions between Local Group dwarfs and larger galaxies have been observed in the past, present, and future. These interactions may have contributed to the gradual assembly of the larger Local Group galaxies. New limitations on the dwarf/giant connection and interaction models are provided by

recent observations of the star-formation histories, space movements, three-dimensional morphologies, and interior kinematics of several of these interacting dwarfs in the Local Group [31, 32].

Small galaxies with a few billion stars make up dwarf galaxies. Dwarf galaxies typically have only a few billion stars as opposed to their larger cousins, which might have hundreds of billions of stars. Many of these dwarf galaxies are in the vicinity of bigger galaxies like the Milky Way or the Andromeda Galaxy. They are believed to have formed from streams of matter and dark matter that were ejected from the parent galaxies during the early stages of the formation of these larger galaxies, or as a result of collisions between galaxies. At least 14 dwarf satellite galaxies orbit the Milky Way galaxy. They may be modern variations of some of the distant galaxies seen in deep field galaxy surveys, and as such, they can aid in our understanding of the early phases of galaxy and star formation in the young Universe.

Dwarf galaxies are regarded to be crucial to our understanding of the entire evolution of galaxies, which stands in stark contrast to their unspectacular appearance. Dwarf irregulars are assumed to be akin to the first galaxies that inhabited the Universe since they often have low metallicities and vast amounts of gas.

When compared to more massive galaxies, dwarf galaxies, with masses below a few billion solar masses, frequently exhibit a larger percentage of dark to luminous matter. There are connections between dwarf galaxies and other domains that have recently come to light due to recent improvements in understanding. The emergence of the earliest stars, the chemical enlargement of the cosmos, the expansion of galaxies and the production of black holes therein, as well as the existence and characteristics of dark matter, are some of these.

Whether these dwarf galaxies are leftovers of the early Universe that were unable to enlarge to the scale of Milky Way-like galaxies or the outcome of different processes (such as mergers, gas or star stripping, or other processes) is unknown. Regardless of where they came from, dwarf galaxies have become important tools for understanding the development of galaxies and serving as rigorous tests for the prevalent cosmological CDM (lambda cool dark matter) model.

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DWARF GALAXIES AS A PROBE OF ΛCDM

There appear to be differences between what is expected and what is observed (for instance, the "missing satellites" problem and the existence of planes of satellites), despite the fact that the number density, mass distribution, and spatial distribution of dwarf galaxies around massive galaxies are among the key predictions of the CDM.Due to the fact that their dynamical mass (determined by kinematic data) exceeds their baryonic (gas and matter) mass, dwarf galaxies are ideally suited for testing dark matter theories. Star-forming dwarf galaxies have a modest scatter around them and extend the dynamical principles of spiral galaxies, suggesting a close link between baryons and dark matter.

The definition of a "dwarf galaxy," as it is usually recognised, is based on luminosity rather than size. It is obvious that dwarfs must be small and dim compared to big galaxies the size of the Milky Way and luminous and extended compared to globular clusters that are older than those seen in the Galaxy. Small galaxies are frequently distorted by interactions, and they are occasionally severely stretched. In order to distinguish between dwarf galaxies, luminosity—rather than size—is frequently used as a criterion. Even while mass-to-luminosity ratios might vary significantly depending on the existence or absence of young massive stars, in the event of minimal dust obscuration, this is also a sign of mass [33].

DWARF GALAXIES: GENERAL PROPERTIES

Morphological Types

Dwarf ellipticals (dEs), a common subclass of early-type galaxies, are characterised by their central projected velocity dispersion, a linear scale (such as the "core," "half-light," or "effective" radius), and a surface brightness (averaged over the core, half-light, or effective radius). These features together define a "fundamental plane" in three dimensions. However, they differ significantly from giant ellipticals in that they closely resemble an exponential light distribution rather than the de Vaucouleurs r 1/4 and become more diffuse as luminosity decreases. Due to changes in the mass-to-luminosity ratios and structural features, these smaller galaxies also do not inhabit the same basic plane and display a bigger scatter in their properties [34, 35].

Dwarf spheroidal galaxies (dSphs) are common in the Local Group. They are dim, elusive, frequently devoid of a detectable interstellar medium, and far more extensive than globular clusters, hence they are not the main focus of this review. They often did not start to produce stars until a few hundred million years ago or more [36].There are 'late-type' galaxies as well as 'early-type' galaxies that are low luminosity and frequently have a surface brightness profile that is exponential. The closest of them are the Small Magellanic Cloud (SMC) and NGC 6822, and they are referred to as dwarf irregular galaxies (dIrrs). A recent collision with another galaxy gave some of them, including the SMC, their distinctive shapes.

Quiescent dIrr galaxies can often be hard to tell apart from their dE counterparts. Additionally, there are actual transient things, such as the Phoenix system [37]. Former late-type systems that have lost their gas in a crowded environment can be early-type dwarfs [38, 39]. There are a number of dIrr galaxies in the Local Group, but blue compact dwarf galaxies (BCDs) are far less common; only one such object, IC 10, has been proposed to be present in the volume of the Local Group [40].

Physical and Chemical Boundary Conditions

The primary distinctions between dwarf and large galaxies' ISMs. For dwarfs:

a. The interstellar medium (ISM) is metal poor.
b. Gravity is weak.
c. Interstellar pressure is low.
d. As a consequence, disks tend to be thick and diffuse.
e. Low gravity and pressure may lead to strong feedback effects.
f. There is little shear due to rotational effects.
g. There is no high-contrast spiral structure shocking and compressing the gas.
h. Dust to gas mass ratios (Md/Mg) are low.
i. Insufficient dust shielding leads to a harsh environment for molecular species.
j. Low Md/Mg ratios lead to a low gas phase depletion of refractory elements ontodust grains.

Metallicities are primarily inferred from the optical spectra of HII areas for mass-metallicity and luminosity-metallicity correlations (Figure 1), [41-44]. Dwarfs have low rotation speeds, well below Vrot = 100 km s-1, due to their modest masses, which suggests that random dynamical events can have a major impact on the detailed velocity field. Late-type dwarf irregulars typically exhibit rotation, albeit occasionally at extremely low rates (Vrot/ 1;: velocity dispersion [45]).

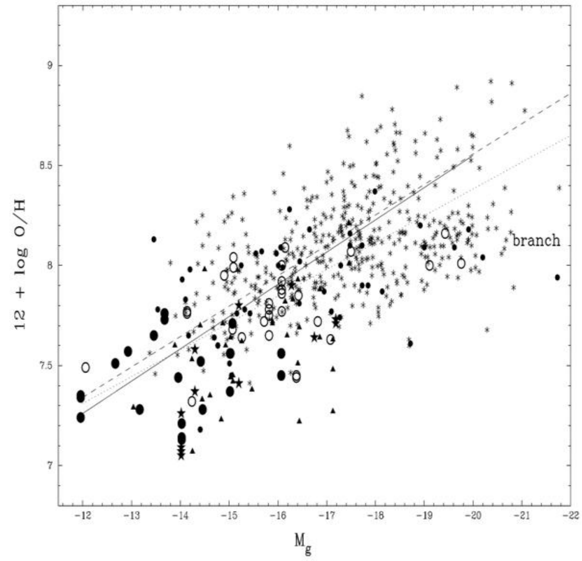

Figure1. Oxygen abundances of mostly local galaxies as a function of absolute g-magnitude. 'Branch' on the right-hand side indicates particularly distant objects (z > 0.2). Small filled circles: data from [46,47]; large filled circles: data from [48]; asterisks: a Sloan Digital Sky Survey (SDSS) sample; open circles: 3.6 m ESO data; stars: VLT data; triangles: additional VLT data from [49]. For more details, see [41].

CONCLUSION

Dwarf galaxies have emerged as invaluable tools for studying fundamental astrophysical processes, galaxy formation, and cosmology.Dwarf galaxies exhibit a wide range of properties, including variations in size, morphology, metallicity, and star formation activity. They are the most abundant galaxy type in the universe, accounting for a significant fraction of the cosmic stellar mass density.Observations of dwarf galaxies have consistently shown a significant disparity between their observed mass and the visible matter they contain. This has led to the conclusion that dwarf galaxies are dominated by dark matter, suggesting a fundamental role for dark matter in the formation and evolution of galaxies.Studying dwarf galaxies provides insights into the nature of dark matter, the early stages of galaxy formation, and the reionization of the universe. They serve as powerful probes for testing cosmological models and constraining the properties of dark matter particles.Dwarf galaxies continue to be fascinating objects that hold the key to unlocking the mysteries of galaxy evolution, dark matter, and cosmology.

REFERENCES

[1]. Whiting AB, Irwin MJ, Hau GKT. 1997. AJ 114:996-1001.
[2]. Marzke RO, Da Costa LN. 1997. AJ 113:185-196.
[3]. Ellis RS. 1997. ARAA 35:389-443.
[4]. Reaves, G., 1983. Astrophys. J. Suppl, 53, 375.
[5]. Binggeli, B., Sandage, A. &Tammann, G. A., 1985. Astr. J., 90,1681 (BST).
[6]. Phillipps, S., Disney, M. J., Kibblewhite, E. J. &Cawson, M. G. M., 1987. Mon. Not. R. astr. Soc., 229, 505.
[7]. Pritzl, B. J., Venn, K. A. & Irwin, M. 2005, AJ, 130, 2140.
[8]. Skillman, E. D., Kennicutt, R. C. & Hodge, P. W. 1989, ApJ, 347, 875.
[9]. Dabringhausen, J., Hilker, M. &Kroupa, P. 2008, MNRAS, 386, 864.
[10]. Belokurov, V. et al. 2006, ApJ, 642, L137.
[11]. Odenkirchen, M. et al. 2001, ApJ, 548, L165.
[12]. Geisler, D. et al. 2007, PASP, 119, 939.
[13]. Kirby, E. N. et al. 2008, arXiv:0807.1925.
[14]. Strigari LE, Bullock JS, Kaplinghat M, Simon JD, Geha M, et al. 2008. Nature 454:1096–1097.
[15]. Bovill MS, Ricotti M. 2009. ApJ 693:1859–1870.
[16]. Safarzadeh M, Ji AP, Dooley GA, Frebel A, Scannapieco E, et al. 2018. MNRAS 476:5006–5015.
[17]. Jethwa P, Erkal D, Belokurov V. 2018. MNRAS 473:2060–2083.
[18]. Karachentseva VE, Karachentsev ID, B¨orngen F. 1985. A&AS 60:213-227.
[19]. Miller BW. 1996. AJ 112:991-1008.
[20]. Cˆot´e S, Freeman KC, Carignan C, Quinn PJ. 1997. AJ 114:1313-1329.
[21]. Sandage A, Binggeli B. 1984. AJ 89:919-931.
[22]. Sandage A, Carlson G. 1985b. AJ 90:1464-1473.
[23]. Ferguson HC, Sandage A. 1991. AJ 101:765-782.
[24]. Phillips S, Parker QA, Schwartzenberg JM, Jones JB. 1998. ApJ 493: L59-L62.
[25]. Bothun GD, Mould JR, Caldwell N, MacGillivray HT. 1986. AJ 92:1007-1019.
[26]. Binggeli B. 1994. In Panchromatic View of Galaxies, ed. G Hensler, C Theis, J Gallagher, p. 173-191. Paris: Editions Frontieres.
[27]. Skillman ED, Bender R. 1995. RevMxA&A Conf Series 3:25-30.
[28]. Gregg M, Minniti D. 1997. PASP 109:1062-1067.
[29]. Ashman K. 1992. PASP 104:1109-1138.
[30]. Mateo M. 1997. In The Nature of Elliptical Galaxies, ed. M Arnaboldi, GS Da Costa, P Saha, p. 259-269. San Francisco: ASP, Vol 116.
[31]. Unavane M, Wyse RFG, Gilmore G. 1996. MNRAS 278:727-736.
[32]. Mateo M. 1996. See Morrison &Sarajedini 1996, p. 434-443.
[33]. Izotov, Y.I.; Guseva, N.G.; Fricke, K.J.; Henkel, C. The bursting nature of star formation in compact star-forming galaxies from the Sloan Digital Sky Survey. Mon. Not. R. Astron. Soc. 2016, 462, 4427–4434. [CrossRef].
[34]. Nieto, J.L.; Bender, R.; Davoust, E.; Prugniel, P. The low-mass extension of the fundamental plane of elliptical galaxies. Astron. Astrophys. 1990, 230, L17–L20.
[35]. Aguerri, J.A.L.; González-García, A.C. On the origin of dwarf elliptical galaxies: The fundamental plane. Astron. Astrophys. 2009, 494, 891–904. [CrossRef].
[36]. Tolstoy, E.; Hill, V.; Tosi, M. Star formationn histories, abundances, and kinematics of dwarf galaxies in the Local Group. Annu. Rev. Astron. Astrophys. 2009, 47, 371–425. [CrossRef].
[37]. Ferguson, H.C.; Binggeli, B. Dwarf elliptical galaxies. Annu. Rev. Astron. Astrophys. 1994, 6, 67–122. [CrossRef].
[38]. Kormendy, J. Families of ellipsoidal stellar systems and the formation of dwarf elliptical galaxies. Astrophys. J. 1985, 295, 73–79. [CrossRef].
[39]. Jaiswal, S.; Omar, A. HI imaging of dwarf star-forming galaxies: Masses, morphologies, and gas deficiencies. Mon. Not. R. Astron. Soc. 2020, 498, 4745–4789. [CrossRef].
[40]. Richer, M.G.; Bullejos, A.; Borissova, J.; McCall, M.L.; Lee, H.; Kurtev, R.; Georgiev, L.; Kingsburgh, R.L.; Ross, R.; Rosado, M. IC 10: More evidence that it is a blue compact dwarf. Astron. Astrophys. 2001, 370, 34–42. [CrossRef].

[41]. Guseva, N.G.; Papaderos, P.; Meyer, H.T.; Izotov, Y.I.; Fricke, K.J. An investigation of the luminosity-metallicity relation for a large sample of low-metallicity emission-line galaxies. Astron. Astrophys. 2009, 505, 63–72. [CrossRef].

[42]. Tremonti, C.A.; Heckman, T.M.; Kauffmann, G.; Brinchmann, J.; Charlot, S.; White, S.D.; Seibert, M.; Peng, E.W.; Schlegel, D.J.; Uomoto, A.; et al. The origin of the mass-metallicity relation: Insights from 53000 star-forming galaxies in the Sloan Digital Sky Survey. Astrophys. J. 2004, 613, 898–913. [CrossRef].

[43]. Gonçalves, T.S.; Basu-Zych, A.; Overzier, R.A.; Pérez, L.; Martin, D.C. Molecular gas properties of UV bright star-forming galaxies at low redshift. Mon. Not. R. Astron. Soc. 2014, 442, 1429–1439. [CrossRef].

[44]. Izotov, Y.I.; Guseva, N.G.; Fricke, K.J.; Henkel, C. On the universality of luminosity-metallicity and mass-metallicity relations for compact star-forming galaxies at redshifts $0 < z < 3$. Mon. Not. R. Astron. Soc. 2015, 451, 2251–2262.

[45]. Roychowdhury, S.; Chengalur, J.N.; Karachentsev, I.D.; Kaisina, E.I. The intrinsic shape of dwarf galaxies. Mon. Not. R. Astron. Soc. 2013, 436, L104–L108. [CrossRef].

[46]. Izotov, Y.I.; Stasi ´nska, G.; Guseva, N.G.; Thuan, T.X. Abundance patterns in the low-metallicity emission-line galaxies from the Early Data Release of the Sloan Digital Sky Survey. Astron. Astrophys. 2004, 415, 87–94. [CrossRef].

[47]. Izotov, Y.I.; Thuan, T.X. Systematic effects and a new determination of the primordial abundance of 4He and dY/dZ from observations of Blue Compact Galaxies. Astrophys. J. 2004, 602, 200–230. [CrossRef].

[48]. Izotov, Y.I.; Thuan, T.X. MMT observations of new extremely metal-poor emission-line galaxies in the Sloan Digital Sky Survey. Astrophys. J. 2007, 665, 1115–1128. [CrossRef].

[49]. Guseva, N.G.; Izotov, Y.I.; Papaderos, P.; Fricke, K.J. Balmer jump temperature determination in a large sample of low-metallicity HII regions. Astron. Astrophys. 2007, 464, 885–893. [CrossRef].