1. INTRODUCTION

The standard model of galaxy formation and evolution includes hierarchical merging/clustering, where smaller structures are used as building blocks of more massive galaxies, and evolution through accretion from cosmological gas filaments in the cosmic web (e.g., Combes 2004; Dekel et al. 2009a, 2009b; Nuza et al. 2014a; Sánchez Almeida et al. 2014b). Because merger events are generally responsible for the disruption of gas and stellar aggregates, they have been traditionally associated with the triggering of supermassive black hole accretion at the center of galaxies (Active Galactic Nuclei activity; Springel et al. 2005; Di Matteo et al. 2008; Hopkins et al. 2008), and with the generation of star formation episodes (e.g., Sanders et al. 1988; Robaina et al. 2009). However, the contribution of cosmological cold-accretion flows to galaxy evolution in general, and star formation in particular, is recently gaining ground. Indeed, cosmological accretion onto galaxies of external metal-poor gas is predicted by numerical simulations to be the main mode of galaxy and disk assembly, at high, and possibly also at low, redshift (Birnboim & Dekel 2003; Brooks et al. 2009). The theory predicts that these cosmological filaments are the main process by which star formation is fed and triggered at all cosmological times (Brooks et al. 2009; Verbeke et al. 2014). Cosmological gas accretion should have been more common at high redshift, but in the local universe, it is hypothesized to intervene in the evolution of individual low-mass galaxies in low-density environments, via small-scale gas streams, facilitating the arrival of gas from large distances (Kereš et al. 2005; Dekel & Birnboim 2006; Brooks et al. 2009; Dekel et al. 2009a, 2009b; Ceverino et al. 2010, 2014; Nuza et al. 2014a).

There has been some observational evidence for these accretion flows at high redshift, from the detection of inverse metallicity gradients (lower metallicity in the central star-forming regions than in the periphery of the sources; Cresci et al. 2010) and from high-column density H I absorbers (e.g., van de Voort et al. 2012). However, in the local universe, there has only been indirect evidence for these events, mainly from the study of star formation in dwarf galaxies. For example, for galaxies of the same mass, the metallicity was shown to decrease when star formation increases (Lara-López et al. 2010; Mannucci et al. 2010; Pérez-Montero et al. 2013). It was also found that metallicities in quiescent blue compact dwarf (BCD) galaxies are higher than those of star-forming BCDs (Sánchez Almeida et al. 2008, 2009). More recently, observations of tadpole galaxies in the Kiso survey of UV-bright galaxies (Elmegreen et al. 2013) and extremely metal-poor dwarf star-forming galaxies (XMPs) have shown that the regions where star formation occurs possess a lower metallicity than the underlying galaxy (Sánchez Almeida et al. 2013, 2014a). From the H I data, it has been shown that local BCDs and XMPs are generally surrounded by pools and streams of H I gas, over three times larger than the optical extension, which frequently display, in the peripheries, distorted and lopsided H I distributions and velocities (Begum & Chengalur 2003; Young et al. 2003; Tuan et al. 2004; Begum et al. 2006; Chengalur et al. 2006; Ekta et al. 2006.
2008, 2009; Walter et al. 2008; Ekta & Chengalur 2010; Ott et al. 2012; Lelli et al. 2012a, 2012b, 2014a, 2014b; Beccari et al. 2014). Furthermore, significant quantities of metal-poor, large-scale H\textsc{i} gas were found in the subset of XMPs (Filho et al. 2013; hereinafter Paper I). Because the gas in galaxy disks is diluted in a relatively small timescale (of the order of one galaxy rotation; e.g., de Avillez & Mac Low 2002; Yang & Krumholz 2012), this cumulative evidence suggests that the gas had to have been accreted recently, most likely as vestigial streams of cosmological accretion (Sánchez Almeida et al. 2014b), like the streams modeled in high-mass galaxies (Dekel et al. 2009a, 2009b; Ceverino et al. 2010, 2014). The rationale is that the metallicity of the accreted H\textsc{i} gas is low. As this gas is fed to the star formation regions of the source, the overall metallicity in this region is lowered, due to dilution of the gas, while elsewhere in the galaxy, the H\textsc{i} gas has been enriched with metals from stellar winds and supernovae from previous star formation episodes.

Thus, XMPs may constitute the ideal local laboratories to probe the role of cosmological accretion flows in galaxy evolution and star formation. XMPs comprise over 0.1% of the galaxies in the local volume (Morales-Luis et al. 2011), and represent the low-metallicity end of the most metal-poor galaxies, below an arbitrarily defined metallicity of one-tenth solar, or 12 + log(O/H) $\lesssim$ 7.65. Although most XMPs are a subsample of star-forming BCDs (Sargent & Searle 1970; Thuan & Martin 1981; Papaderos et al. 1996a, 1996b; Telles & Terlevich 1997; Kunth & Óstlin 2000; Cairós et al. 2001, 2003; Bergvall & Óstlin 2002; Noeske et al. 2003; Gil de Paz & Madore 2005; Amorín et al. 2007, 2009; Muchiya et al. 2013), some XMPs are more diffuse and correspond to the crowns of dwarf irregular galaxies (e.g., Skillman et al. 2013). They contain copious amounts of metal-poor, unsettled, H\textsc{i} gas (Begum & Chengalur 2003; Young et al. 2003; Thuan et al. 2004; Begum et al. 2006; Chengalur et al. 2006; Ekta et al. 2006, 2008, 2009; Walter et al. 2008; Ekta & Chengalur 2010; Lelli et al. 2012a, 2012b, 2014a, 2014b; Paper I; Ott et al. 2012). Moreover, in $\sim$80% of the cases, XMPs show evidence for optical asymmetry (Papaderos et al. 2008; Morales-Luis et al. 2011; Paper I). The lopsided optical morphology has been commonly interpreted as asymmetric star formation, occurring in a galaxy/disk that is in a transient phase (Papaderos et al. 2008; Elmegreen 2009; Elmegreen & Elmegreen 2010), a rare occurrence at low redshift.

The objective of this paper (Paper II) is to analyze the environment of the XMPs, with the aim of understanding the role of cosmological accretion flows in the galaxy/disk assembly and triggering/feeding of the star formation in XMPs. Archival high resolution interferometric H\textsc{i} data are used to investigate the nearby environment, whereas cosmological simulations constrained by observations, and the observed distribution of galaxies, provide information on the environment on large scales. The sources are the same as in Paper I, and have been taken from the parent sample of 140 local XMPs, selected by Morales-Luis et al. (2011), from the Sloan Digital Sky Survey (SDSS) Data Release (DR) 7 (Abazajian et al. 2009) and literature. For 20 XMPs, archive H\textsc{i} imaging, at resolutions higher than 1′, is available via interferometric Very Large Array (VLA) and/or Giant Metrewave Radio Telescope (GMRT) observations; these are used to probe the nearby environment. The cosmic web environment is inferred from the constrained numerical simulations by Heß et al. (2013) and Nuza et al. (2014b), and the catalog of SDSS galaxy filaments assembled by Tempel et al. (2014). We have also searched for close companions to the XMPs in the SDSS database.

The paper is organized as follows. In Section 2 we present a summary of the optical and H\textsc{i} properties of XMPs with archival high resolution H\textsc{i} observations, which includes an analysis of the small-scale environment. Section 3 contains our investigation of the large-scale environment of XMPs in light of three diagnostic tools: cosmic web type, overdensity and nearest neighbors. In Section 4 we discuss the results and present the conclusions. The Appendix contains a qualitative description of the archival high resolution H\textsc{i} morphology and velocity field of individual XMPs.

## 2. SMALL-SCALE ENVIRONMENT

Of the 140 local XMPs in the parent sample, 29 sources with no H\textsc{i} information have been observed with the single-dish Effelsberg radio telescope, resulting in 11 new detections (Paper I). Overall, 53 XMPs possess H\textsc{i} data in literature; but of these, only 20 have been observed at high spatial resolution ($\lesssim$1′), with either the GMRT or the VLA. We use these archival H\textsc{i} observations to investigate the spatial and dynamical distribution of the H\textsc{i} gas, and its relation to the optical component, which can provide clues as to the origin of the observed XMP properties.

### 2.1. XMPs with Archival High Resolution H\textsc{i} Observations

Lelli et al. (2014a, 2014b) have presented a detailed quantitative assessment of the H\textsc{i} properties (from new and archival data) of 18 starburst dwarf galaxies, four of which are also in our XMP sample (UGC 4483, UGC 6456, IZw 18, and SBS 1415+437). In this paper, we attempt only a qualitative description of the high resolution H\textsc{i} data in literature, in order to obtain global statistical properties for the XMP sample.

In Table 1 we present a summary of the optical properties of the sample of 20 local XMPs with archival high resolution interferometric H\textsc{i} observations. The data are adapted from Table 3 of Paper I, with some revision and description of the optical morphology. Table 2 provides a summary of the relevant H\textsc{i} properties, at several scales, of the 20 local XMPs with archival high resolution interferometric H\textsc{i} observations. The properties are a compilation of interferometric H\textsc{i} data from literature, namely VLA and GMRT data. Low resolution maps display resolutions $\gtrsim$30″, while intermediate resolution display 30–15″ and high resolution display $\lesssim$15″.

In the Appendix, we present a detailed description of the H\textsc{i} high resolution data for each XMP.

If we compare the XMP H\textsc{i} morphology and velocity field with the classification given in Lelli et al. (2014b), we conclude that almost all of the XMPs fall within their classification of Type A/B sources—galaxies with regularly rotating H\textsc{i} disks/galaxies with kinematically disturbed H\textsc{i} disks. That is, the XMPs generally show an H\textsc{i} disk-type morphology, with a velocity field typical of a rotating disk, which may present some small asymmetries and irregularities in the outskirts, and which may be (only slightly) off-center relative to the optical peak and/or star-forming knots; statistically, we do not observe significant perturbations in the large-scale H\textsc{i} gas component of the XMP population (Appendix). High spatial resolution observations of the H\textsc{i} gas suggest feeding of the star formation regions; the gas is...
resolved into complex substructure, with the gas “pointing at” or “cradling” bright star-forming regions, or showing signs of “clearing” around the star-formation knots (Appendix). J0956+2849 (Èktå et al. 2008 and Appendix) and Sag Dig (Becceï et al. 2014 and Appendix) have been suggested to be the result of a merger process. J0956+2849 shows two H i “Spiral arms”, while Sag Dig’s H i morphology is ring-like, with an off-center depression, and the velocity field displays no sign of rotation. These features are generally not found in XMPs, which we interpret as evidence that the XMPs, as a class, are currently not undergoing a major interaction or merger. Rather, the asymmetries and irregularities of the outer envelope are understood as signs of weaker interactions caused by minor mergers, gas accretion or gas outflows driven by galactic winds.

3. LARGE-SCALE ENVIRONMENT

In order to investigate the environment in which XMPs occur, and the influence that cosmological accretion flows may have on their evolution and observed properties, we have computed the likelihood of an XMP to inhabit a certain type of environment using three diagnostics: cosmic web type, overdensity and nearest neighbors.

The environment can be classified according to local indicators, such as the local density, or according to non-local
Table 2

Summary of the H I Data of the 20 Extremely Metal-poor Galaxies in the Local Universe with Archival High Resolution Interferometric H I Observations

| Source Name          | PA_{opt} | H I/opt Ratio | H I/opt Offset | PA_{H I} | PA_{VEL} | Note | References |
|----------------------|----------|---------------|----------------|----------|----------|------|------------|
| J0119-935            | 115      | 4             | 10/10          | 120–110  | 120      | ...  | 1          |
| UM 133               | 105      | 2             | 0/10           | 105      | 105      | ...  | 1          |
| SBS 0335-052W        | ...      | 6             | 10/10          | 150      | NE-SW–N-S| P    | 2          |
| SBS 0335-052E        | 45       | 4             | 10/10          | 145–20   | NE-SW    | P    | 2          |
| UGC 4305             | 115      | 5             | 00             | ...      | ...      | 3    |            |
| HS 0822+03542        | 45       | 10            | 10/10          | 70–80    | 70       | P    | 4          |
| DD 053              | 55       | 3             | 10/10          | 150      | 45       | ...  | 3,5        |
| UGC 4483             | 80       | 2             | 10/0           | 80–60–80 | 90–120   | ...  | 6,7,8,9    |
| Izw 18              | 45       | 7             | 10/0           | 45       | 50–55    | P    | 8,9,10     |
| J0956+2849           | 115      | 6             | 20/0           | 105      | 115      | M    | 11         |
| Leo A                | 10       | 3             | 10/10          | 25       | 130      | ...  | 6          |
| Sextans B           | 25       | 3             | 10/10          | 25       | 130      | ...  | 6          |
| Sextans A           | 45       | 2             | 10/0           | 135      | 150      | ...  | 6          |
| UGC 6456            | 115      | 2             | 10/0           | 75       | 90       | ...  | 8,9,12     |
| SBS 1129+576        | 75       | 2             | 00             | 75–70    | 70       | P    | 13         |
| UGC 292             | 165      | 3             | 00             | 175      | 145      | ...  | 6,14       |
| GR 8                | 130      | 2             | 10/10          | 165      | 80       | ...  | 5,6,14,15  |
| SBS 1415+437        | 120      | 2             | 10/0           | 115      | 115      | ...  | 8,9        |
| Sag Dg              | 170      | 6             | 00             | ...      | ...      | M    | 5,16       |
| J2104-0035          | 110      | 5             | 10/10          | 90       | 90       | ...  | 17         |

Notes. Columns: Col. 1: Source name. Col. 2: Approximate position angle of the largest optical extension, measured counterclockwise from the west, from the SDSS DR10 or DSS images. Col. 3: Approximate H I-optical ratio, where the H I extension is measured in the lowest resolution interferometric map. Col. 4: Approximate offset between the H I peak and the optical center/brightest star-forming knot. Col. 5: Approximate position angle of the largest H I extension, measured counterclockwise from the west (from the lowest to highest resolution map). Col. 6: Possible interaction/merger of the XMP. "P" designates a galaxy that belongs to a confirmed interacting pair. "M" designates a galaxy that may have undergone a recent merger. Col. 8: Reference, with interferometer data and/or survey. Instrument, interferometer and survey acronyms:

GMRT—Giant Metrewave Radio Telescope.
VLA—Very Large Array.
THINGS—The H I Nearby Galaxy Survey.
ACS—Advanced Camera for Surveys.
ANGST—ACS Nearby Galaxy Survey Treasury.

Reference in column 8:
(1)—Ekta & Chengalur (2010); GMRT.
(2)—Ekta et al. (2009); GMRT.
(3)—Walter et al. (2008); THINGS.
(4)—Chengalur et al. (2006); GMRT.
(5)—Begum et al. (2006); GMRT.
(6)—Ott et al. (2012); VLA ANGST.
(7)—Lelli et al. (2012b); VLA.
(8)—Lelli et al. (2014b); VLA.
(9)—Lelli et al. (2014b); VLA.
(10)—Lelli et al. (2012a); VLA.
(11)—Ekta et al. (2008); GMRT.
(12)—Thuan et al. (2004); VLA.
(13)—Ekta et al. (2006); GMRT.
(14)—Young et al. (2003); VLA.
(15)—Begum & Chengalur (2003); VLA.
(16)—Beccari et al. (2014); VLA.
(17)—Ekta et al. (2008); GMRT.

* SBS 0335-052E and SBS 0335-052W are an interacting pair. Due to lack of resolution, the PA_{VEL} is merely indicative.

indicators, based, for example, on the tidal-field tensor. In the first case, one can estimate the local overdensity based solely on observations, defined as the number density of galaxies relative to the background number density, or by characterizing the nearest neighbors (type, mass, number and distance). However, a classification of the environment into its cosmic web components requires knowledge of the large-scale environment. The sign of the eigenvalues of the tidal-field tensor indicates pure contracting regions, such as clusters or knots, or expanding regions in three, two, or one dimensions, representing voids, sheets, or filaments, respectively (Hahn et al. 2007). While numerical simulations provide all the necessary information to perform a cosmic web analysis, observations require a prior reconstruction of the large-scale matter density field. The particular reconstruction technique will determine the accuracy of the cosmic web classification.
3.1. Cosmic Web Type and Overdensity

We here rely on precise constrained $N$-body simulations of the local universe, using the Two-Micron All-Sky Galaxy Redshift Survey (2MRS; Huchra et al. 2012), within volumes of $180 h^{-3} \text{Mpc}^3$ (Heß et al. 2013). Cosmological parameters only provide a statistical description of the universe, so that an infinite number of realizations are consistent with the same set of parameters. The procedure provides a cosmological simulation, which reproduces, in detail, the spatial distribution of galaxies in the local universe as described by 2MRS. The method to reconstruct the initial fluctuations used in these simulations is based on a self-consistent Bayesian machine-learning algorithm, reaching an accuracy of $\sim 2 \text{Mpc} h^{-1}$ (Kitaura et al. 2012; Heß et al. 2013; Kitaura 2013). The cosmic web classification used in this study has been performed following Forero-Romero et al. (2009), based on the best correlated constrained $N$-body simulation with the 2MRS galaxy field (Nuza et al. 2014b). The overdensity ($\delta$) used in this study has been computed from the same constrained simulation. The preference of a type of galaxy to be located in a particular environment is quantified by $\eta(\tau, \epsilon)$, an excess probability ratio, where $\tau$ is the galaxy type and $\epsilon$ is the cosmic web environment type (voids, sheets, filaments and knots; Nuza et al. 2014b). The environment (overdensity or cosmic web type) of a source can be assigned according to the cell in the reconstruction where the source is located. Each cell is characterized by three coordinates: right ascension, declination, and redshift, with the redshift parameterizing the distance, including the proper motions caused by local tidal fields, taken consistently into account.

Because we possess coordinates for our XMP galaxies, we have used the constrained simulation to determine the type of environment (cosmic web type and overdensity) in which the XMPs reside. Spectroscopic redshifts from the SDSS DR10 (Ahn et al. 2012) are available for $\sim 70\%$ of the 140 XMPs. For the remaining XMPs, photometric redshifts from the SDSS DR 10 or NASA/IPAC Extragalactic Database7 (NED) were used.

In Figure 1, we have compared the cosmic web type environment distribution of XMPs with other galaxy morphological types, namely, ellipticals (E), lenticulars (S0), spirals (Sp), and irregular galaxies (Irrs), as assigned by the 2MRS team (Huchra et al. 2012). Although the Poisson error bars are larger for the XMP sample, it is apparent that the XMPs follow similar trends as Irr galaxies, but with a more pronounced behavior (Figure 1). The XMP prevalence in voids and sheets, and the avoidance of knots, suggests that, statistically and on a large scale ($\sim 1 \text{Mpc}$), the XMPs are relatively isolated (Figure 1).

As a consistency check, we have also estimated the cosmic web type distribution for a large sample of control galaxies ($\sim 700 \text{BCDs}$, with $Z > 0.1 Z_\odot$) from the SDSS DR8 (Aihara et al. 2011). We find a similar behavior among the BCDs and

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7 http://ned.ipac.caltech.edu/
XMP sample, which is markedly different from the environments found for E, S0, and Sp galaxies, and more extreme than the behavior of the Irr galaxies in the zero redshift 2MRS sample (to be included in a future paper).

Figure 2 shows the projected spatial distribution of the 140 local XMPs, color-coded by cosmic web type. The sizes of the circles trace the overdensity, such that, the larger the circle, the larger the overdensity. The values range from the most underdense ($\delta = -0.9$, for PHL 293B) to the most overdense ($\delta = 376$, for VCC 0428, a BCD in the Virgo cluster; Meyer et al. 2014) source environment. Figure 3 shows the overdensity distribution ($\log(1+\delta)$), color-coded by cosmic web type, for the XMP sample. Arrows, color-coded by cosmic web type, show the mean overdensity ($\log(1 + \langle \delta \rangle)$) for each distribution. According to the overdensity distribution, $\sim$60% of the XMPs are found in underdense regions ($\delta \leq 0$) of the reconstruction (Figures 2 and 3). On the other hand, most of the XMP galaxies ($\sim$75%) reside in the less dense cosmic web type environments ($\sim$40% are in sheets and $\sim$34% in voids), while $\sim$25% can be found in filaments, and $\lesssim$1% in knots (Figures 1, 2, and 3).

In the analysis below, because we are constrained by small number statistics and systematic errors that may affect the determination of the physical parameters, the trends should be taken with caution.

We have investigated whether the H\textsc{i} mass ($M_{\text{HI}}$), dynamical mass ($M_{\text{Dyn}}$), or stellar mass ($M_*$) of the XMPs depends on the environment in which they reside (Figure 4). The H\textsc{i} and stellar masses were taken from Table 5 of Paper I. In this Paper II, we have estimated the dynamical masses with revised optical radius measurements. There is a large overlap in dynamical, H\textsc{i}, and stellar mass for a range of overdensities (Figure 4). However, XMPs in filaments and sheets show the largest range in H\textsc{i} mass, particularly extending to lower H\textsc{i} masses, while XMPs in voids show tendentially larger H\textsc{i} masses, above $\log(M_{\text{HI}}/M_*) \approx 7$ (Figure 4(a)). Five sources in voids and sheets show the largest dynamical masses ($\log(M_{\text{Dyn}}/M_*) \gtrsim 9$; Figure 4(b)). In terms of stellar mass, most XMPs in filaments found in underdense regions ($\delta \geq 0$) show stellar masses below $\log(M_*/M_*) \approx 7$, with a tail of XMPs in less dense filamentary environments toward high stellar masses ($\log(M_*/M_*) \gtrsim 8$; Figure 4(c)). The largest H\textsc{i}-to-stellar, mass ratio belongs to an XMP residing in a void (Figure 4(d)). Overall, we see no clear relation between the environment in which XMPs reside and their dynamical, stellar or H\textsc{i} mass.

We have further investigated if there is an environment trend with metallicity ($12 + \log(O/H)$), star formation rate (SFR), specific star formation rate (sSFR $\equiv$ SFR/$M_*$), H\textsc{i} gas consumption rate ($1/H_{\text{Mol}} \equiv$ SFR/$M_{\text{HI}}$), and optical morphology (symmetric, cometary, two-knot, and multi-knot; Figure 5). These values were taken from Tables 3 and 4 of Paper I. We find no clear correlation between environment and metallicity (Figure 5(a)), SFR (Figure 5(b)), and gas consumption rate (Figure 5(d)). However, XMPs in voids show a slight tendency for larger values of sSFR ($\log(sSFR) \gtrsim -8$yr$^{-1}$; Figure 5(c)). Cometary and multi-knot XMPs are roughly equally (fractionally) prevalent in voids, sheets, and filaments (Figures 5(e) and (f)), while two-knot sources are roughly equally (fractionally) prevalent in voids and sheets (Figures 5(e) and (f)). Symmetric sources are found to be more common in voids (Figures 5(e) and (f)). The two sources with morphological information, and contained in knots, are both cometary (Figures 5(d) and (e)).

In summary, we find that XMPs tend to reside in low-density environments, and in cosmic web types characterized as voids and sheets. We further find that XMPs, BCDs, and Irr galaxies tend to inhabit the same type of environment, which is in stark contrast with the behavior of E, S0, Sp galaxies in the zero redshift 2MRS sample.
3.2. Proximity to SDSS Morphological Filaments

We have investigated the proximity (or inclusion) of XMPs to morphological filaments, i.e., “chains” of galaxies, as empirically defined using galaxies in the spectroscopic sample of the SDSS DR8 dataset. Tempel et al. (2014) use a marked-point process with interactions, called the Bisous model (Stoica et al. 2005), to detect galaxy filaments in the spectroscopic sample of the SDSS DR8 dataset (Tempel et al. 2012). A redshift interval of $0.009 \leq z \leq 0.155$ was used so that the lower redshift limit excludes the Local Supercluster. The authors look for morphological filaments with a radius of $0.5 \, h^{-1} \text{Mpc}$. They find that the shortest filaments in their filament catalog are $3-5 \, h^{-1} \text{Mpc}$ in length, while typical filament lengths are of $60 \, h^{-1} \text{Mpc}$.

We have mined the catalog of galaxies (hereinafter A3), used to generate the morphological filaments, to search for XMP identifications, or, alternatively, to find the nearest galaxy to each XMP. Distances between the XMPs and A3 galaxies were estimated neglecting galaxy proper motions, since the local flow for pairs of nearby galaxies should be of the same order. A3 also includes the distance of each galaxy to the nearest morphological filament (Tempel et al. 2014). Hence, the distance of the nearest galaxy and morphological filament can be used as a proxy for the distance of the XMPs to morphological filaments. In order to identify our sample XMPs in the A3, we searched the A3 for galaxies within $D \sim 10 \, \text{kpc}$ of the XMP positions; none were found. We are, therefore, confident that the nearest galaxy identified for each XMP is truly a separate galaxy. We stress that A3 contains $\sim 500,000$

![Figure 4](image-url)
Figure 5. The overdensity as a function of (a) metallicity, (b) SFR, (c) sSFR, (d) $\frac{\text{SFR}}{M_{\text{HI}}}$, and (e) and (f) optical morphology (symmetric, cometary, two-knot, and multi-knot), color-coded by cosmic web type (blue for voids, red for sheets, green for filaments, and cyan for knots). These parameters were taken from Tables 3 and 4 of Paper I.
SDSS DR8 sources in a contiguous field, which could miss the XMPs and some of their possible neighbors (see below).

Figure 6 contains the XMP distance to the nearest galaxy ($D_{\text{galaxy}}$) in A3, as a function of the distance between the nearest galaxy in A3 and the nearest morphological filament ($D_{\text{filament}}$), color-coded by cosmic web type of the XMP. The solid black lines indicate the radii of the morphological filaments, so that XMPs in galaxy filaments should display $D_{\text{galaxy}} \lesssim 0.5$ Mpc and $D_{\text{filament}} \lesssim 0.5$ Mpc. The black dashed line indicates a representative distance for the nearest galaxy, in order to exert some gravitational influence over the XMP (see Sections 3.3 and 3.4).

Figure 6. The distance between the XMP and the nearest galaxy in A3, as a function of the distance between the nearest galaxy in A3 and the nearest morphological filament, color-coded by cosmic web type of the XMP. The solid black lines indicate the radii of the morphological filaments, so that XMPs in galaxy filaments should display $D_{\text{galaxy}} \lesssim 0.5$ Mpc and $D_{\text{filament}} \lesssim 0.5$ Mpc. The black dashed line indicates a representative distance for the nearest galaxy, in order to exert some gravitational influence over the XMP (see Sections 3.3 and 3.4).

### 3.3. Nearest Galaxies and Potential Perturbers

According to the galaxies in the A3 catalog, only two XMPs have a galaxy within $D_{\text{galaxy}} \lesssim 100$ kpc, with one of these XMPs residing in a filament and another in a void (Figure 6). Indeed, there are four documented XMPs that are known to be interacting with nearby companions (IZw 18, SBS 0335-052, HS 0822+03542, and SBS 1129+576; Section 2). Overall, the nearest galaxies in A3 show a large range in distances to the XMPs ($D_{\text{galaxy}} \sim 0.1$–100 Mpc), which does not seem to depend strongly on the XMP environment (Figure 6). However, there is a tendency for XMPs in filaments to show a somewhat bimodal behavior: there is a group of (nearest) galaxies at smaller ($D_{\text{galaxy}} \lesssim 1$ Mpc) and larger ($D_{\text{galaxy}} \sim 10$ Mpc) distances (Figure 6).

In order to complement the results based on A3, we have also looked for nearest galaxy neighbors, as potential perturbers, using the full SDSS DR9 (Ahn et al. 2012) catalog. The search was performed within a 12′ radius around each XMP, corresponding to a distance of $D \sim 200$ kpc at $z = 0.01$. We further constrained the galaxies to have spectroscopic redshifts of $z < 0.1$, resulting in $\sim 1000$ galaxies, potential perturbers to 104 XMPs. We have also estimated the stellar mass of the potential perturbers from their SDSS DR9 $g - r$ colors, using the mass-to-light ratios from Bell & de Jong (2001).

In Figure 7 we plot the stellar mass ($M_* \equiv 10^9 M_\odot$) and distance ($D_{\text{perturber}}$) of the nearest potential perturber within $D \lesssim 300$ Mpc of the XMPs, color-coded by cosmic web type of the XMP. Only one XMP shows a potential perturber within $D_{\text{perturber}} \lesssim 100$ kpc, with a stellar mass of $M_* \sim 10^7 M_\odot$ (Figure 7). We cannot, however, exclude the presence of potential perturbers with no measured spectroscopic redshift in the SDSS, nor less luminous (and less massive) than the XMPs, due to the magnitude cutoff of the SDSS (magnitude in $r > 17.7$ mag). Comparing Figure 6 and Figure 7, we conclude that the potential biases in the A3 sample do not modify the conclusion that XMPs generally do not have close companion galaxies. Above a $D_{\text{perturber}} \sim 1$ Mpc distance to the XMP, the stellar masses of the nearest potential perturbers show a change; the stellar masses not only span a larger range, but potential perturbers with stellar masses of up to $M_* \sim 10^{11} M_\odot$ can be found (Figure 7). The nearest, least massive, and most massive potential perturbers belong to XMPs in all three major cosmic web types (voids, sheets, and filaments). We further note a break in perturber mass distribution at $D_{\text{perturber}} \sim 10$ Mpc; above this distance, stellar masses are skewed toward the larger range ($M_* \gtrsim 10^9 M_\odot$), consistent with the detection, at larger distances, of more luminous, and hence more massive, galaxies (Figure 7).

Overall, with the exception of the already documented cases of XMPs with companions (Section 2 and Appendix), statistically we do not find evidence for the presence of potential perturbers (with measured spectroscopic redshifts in the SDSS) within $D \lesssim 100$ kpc of the XMPs. We caution, however, that due to a lack of spectroscopic redshift and the spectroscopic flux limit of the SDSS, we may be missing potential perturbers of very low mass and luminosity.

### 3.4. Perturbations and Interactions

Because the nearest galaxies to XMPs are generally found to be at distances $D \gtrsim 100$ kpc (Figures 6 and 7), we have attempted to evaluate the gravitational influence these could have on the XMPs, particularly if they could potentially trigger and/or feed the star formation. As a first approximation, we have analyzed the conditions for perturbation in a system of a satellite galaxy (XMP) on a circular orbit around a perturber. Let us consider that the satellite galaxy has mass $m$ and radius $r$, orbiting a perturber galaxy of mass $M$, at a distance $D$, and where $m \ll M$.

Minor mergers/interactions (when $m \ll M$) occur through dynamical friction, when the perturber and satellite share a common dark matter halo. This dynamical friction causes orbital decay of the satellite galaxy within the so-called dynamical friction timescale (e.g., Patton et al. 2000; Binney &
where $D$ is the distance between the satellite galaxy and the perturber (in kpc), $v$ is the circular speed of the satellite (in km s$^{-1}$), $m$ is the mass of the satellite (in $M_\odot$), and $\ln \Lambda$ is the Coulomb logarithm. This expression does not take into consideration any mass loss (from tidal stripping) that the satellite may suffer during the orbital decay.

If we assume a typical distance to the perturber of $D \approx 100$ kpc (Figures 6 and 7), a satellite mass of $m \approx 10^8 M_\odot$ (Figure 4(c)), a Coulomb logarithm of $2$ (e.g., Binney & Tremaine 2008; Filho et al. 2014), and a circular velocity of the satellite of $v \approx \sqrt{GM/D}$, where $G$ is the gravitational constant, this then yields a dynamical friction timescale of $T_{\text{fric}} \approx 50$ Gyr, for $M \approx m$, or 150 Gyr, for $M \approx 10 m$. This estimate provides a timescale for the satellite to spiral in toward the perturber. The resulting timescales are too long for the merger/interaction process to be significant in XMPs.

As the satellite approaches the perturber on this orbital decay, the tidal forces at work on the satellite become more important. If we now consider a test particle at a distance $\Delta r$ from the surface of the satellite (where $\Delta r \ll r$), then the perturber will exert a perturbative tidal force on the test particle (relative to the force exerted at the center of the satellite), that is given by (e.g., Binney & Tremaine 2008):

\begin{equation}
F_M \approx \frac{2 G M (r + \Delta r)}{D^3} \approx \frac{2 G M r}{D^3}.
\end{equation}

The satellite will also exert a restoring force on the test particle, if tidal forces displace it from its equilibrium configuration at $r$, namely (e.g., Binney & Tremaine 2008):

\begin{equation}
F_m = \frac{G m \Delta r}{r^3},
\end{equation}

where we have neglected the pressure support in the satellite (Adams et al. 2011). In equilibrium $F_M \approx F_m$, therefore, the displacement produced by tidal forces is given by:

\begin{equation}
\frac{\Delta r}{r} \approx 2 \frac{M}{m} \left( \frac{r}{D} \right)^3.
\end{equation}

The condition for tidal disruption of the test particle by the perturber is producing a large perturbation, i.e., $\Delta r/r \gtrsim 1$.

In Figure 8 we show the displacement produced by tidal forces (Equation (4)), as a function of the ratio between the XMP radius and the distance to the perturber, color-coded by the relative XMP/perturber mass. As can be seen from Figure 8, in order for tidal stripping to occur, the perturber is required to have a high mass and/or be located at a small distance to the satellite. For a perturber and satellite of similar mass ($M \approx m$), the distance must be of the order of the size of the galaxy ($D \approx r$). Because XMPs have radii of a few kpc, $D$ must also be a few kpc in order to exert appreciable gravitational influence on the XMP.

Therefore, although a significant number of XMPs show potential perturbers within $D \sim 300$ Mpc, it is unlikely that these will cause major gravitational disturbance (or tidal stripping) of the XMP, which could instigate gas transfer and sustain star formation.

4. DISCUSSION AND CONCLUSIONS

XMPs are found to tendentiously reside in low-density environments ($\sim 60\%$) and in cosmic web types characterized as voids and sheets ($\sim 75\%$; Section 3.1). In this respect, their behavior is extreme, in contrast to the location in the cosmic web of E, S0, and Sp galaxies, but inhabiting regions similar to those of Irrs and BCDs (Section 3.1).

We find results similar to those found for nearby (relatively) luminous galaxies (Blanton & Moustakas 2009) and H$\alpha$-emitting galaxies (Darvish et al. 2014), whereby the environment does not determine the overall observed properties (mass, luminosity, SFR, etc) of a certain galaxy type. However, the fraction of a certain galaxy type (in this case, XMPs) does appear to be determined by the environment in which it resides (Section 3.1).

The evidence for occupation of low-density environments is further strengthened when we investigate the proximity to morphological filaments (Section 3.2), and galaxies in the vicinity of the XMPs (Section 3.3). We find no significant evidence for the presence of galaxy filaments within $D \sim 0.5$ Mpc of an XMP, and only one potential perturber (of mass and luminosity at least equal to that of an XMP, and with a measured spectroscopic redshift in the SDSS) is found within $D \sim 100$ kpc of an XMP. However, even at these distances, we have demonstrated that a potential perturber is very unlikely to cause gravitational disturbance capable of drawing fresh gas or driving the star formation (Section 3.4).

We have also analyzed the small-scale environment, probing for signatures of galaxy merger/interactions in the published H$\alpha$ data of XMPs (Section 2 and Appendix). IzW 18 (Lelli et al. 2012a, 2014a, 2014b), SBS 0335-052W and SBS 0335-052E (Ekta et al. 2009), HS 0822+03542 (Chengalur Section 3.1).
Hints of kinematical and morphological disturbance of the H\textsc{i} gas appear primarily in the galaxy outskirts; tails, extensions, clumps of H\textsc{i} gas, and kinks, discontinuities, twisting of the velocity field (Section 2 and Appendix).

Indeed using three different diagnostic tools (overdensity, cosmic web type, and nearest galaxies/potential perturbers), we find evidence that XMPs are relatively isolated in the nearby universe, on scales of hundreds of kpc (Sections 2 and 3). However, despite this isolation, we must understand how XMPs acquire such large amounts of metal-poor H\textsc{i} gas (Paper I and references therein), and how they sustain their star formation.

An alternative scenario is that XMPs are truly primordial galaxies, in the sense that they have remained quiescent for some time, thus preserving the H\textsc{i} gas acquired early on in their formation. However, this scenario cannot explain the current starburst phase of the XMPs, nor can it explain the reason, or provide a mechanism, for the XMPs to have abandoned their quiescent phase. Moreover, because most XMPs have huge SFRs for their stellar masses (Figure 5c), they would have had to form all their stars in less than a Gyr, at the present rate. Following Sánchez Almeida et al. (2013, 2014b), we find that the XMP properties, particularly their environment characteristics, are consistent with XMP evolution being mainly driven by metal-poor gas accretion, similar to the cold accretion flows simulated at high redshift (Kereš et al. 2005, 2009; Brooks et al. 2009; Dekel et al. 2009a, 2009b; Ceverino et al. 2010, 2014; Nuza et al. 2014a), and supported by observational evidence (Cresci et al. 2010; van de Voort et al. 2012). Such accretion is known to be stochastic, occurring along streams of high density cold gas, which are capable of penetrating low-mass haloes (Kereš et al. 2005, 2009; Brooks et al. 2009; Dekel et al. 2009a, 2009b; Verbeke et al. 2014). Moreover, this cold-mode of accretion is able to explain the major observational properties of the XMPs: the relative isolation (Sections 2 and 3), the lack of recent interaction/merger signatures in the gas and stars (Section 2 and Appendix), the lopsided optical morphology (Papaderos et al. 2008; Morales-Luis et al. 2011; Paper I), the large amount of metal-poor H\textsc{i} gas (Paper I and references therein), the metallicity inhomogeneities (Sánchez Almeida et al. 2013, 2014a), and the recent burst of star formation.

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Figure 8. The displacement produced by tidal forces, as a function of the ratio between the XMP radius and the distance to the perturber, color-coded by the relative XMP/perturber mass: \( M/M_h = 0.1 \) (cyan), 1 (blue), 10 (red), 100 (green). The black line corresponds to \( \Delta r/r = 1 \), the lower limit criteria for tidal stripping.

et al. 2006), and SBS 1129+576 (Ekta et al. 2006) have been confirmed to be interacting with companion galaxies, all within \( D \leq 25 \text{ kpc} \) (Section 2 and Appendix). Moreover, it has been suggested that the H\textsc{i} properties observed in Sag Dig (Beccari et al. 2014) and J0956+2849 (Ekta et al. 2008) could be the result of a recent merger between dwarf galaxies. However, if J0956+2849 and Sag Dig are the result of a merger Section 2 and Appendix), then the merger signatures present in these sources (H\textsc{i} spiral arms, ring-like H\textsc{i} distribution versus disk-like optical morphology, clumpy H\textsc{i} distribution with no optical correspondence, large offset between the optical center and the depression in the H\textsc{i} distribution, no clear rotational motion) are generally absent in the XMP population. Indeed, we find no statistical evidence for (major) interactions with (gas-rich) galaxy companions in the recent past (Section 2 and Appendix; see also Brosch et al. 2004; Holwerda et al. 2013; Kreckel et al. 2015), a mechanism which is traditionally invoked as a driver for star formation and overall galaxy evolution (e.g., Keel et al. 1985; Robaina et al. 2009). Although such an interaction could provide large quantities of fresh H\textsc{i} gas, and create conditions for triggering/feeding the observed star formation, it cannot explain why the gas we observe is metal-poor (Paper I), nor can it explain the metallicity inhomogeneities observed in some XMPs (Sánchez Almeida et al. 2013, 2014a), and it does not explain why we do not systematically observe signatures of major disturbances/interactions in the H\textsc{i} gas, and particularly in the H\textsc{i}-to-optical morphological/kinematical relation (Section 2 and Appendix). In fact, the central regions of the H\textsc{i} structures are relatively well-behaved; in many cases they are organized in a disk with clear rotational motion, in which the kinematical H\textsc{i} axis is virtually aligned (within 15°) with the H\textsc{i} and optical axis, where the peak of the H\textsc{i} emission is positionally coincident (within 10") with the center of the optical disk or the brightest star formation knot (Appendix), and where the velocity offsets between the stellar and H\textsc{i} components are absent or small (< 40 km s\(^{-1}\); of the order of the velocity dispersion; Paper I).
APPENDIX
DESCRIPTION OF XMPS WITH ARCHIVAL HIGH RESOLUTION H I OBSERVATIONS

This Appendix provides a detailed description of the H i properties of the 20 XMPS with high resolution interferometric data in literature. The average properties of these galaxies, as a class, are discussed in Section 2. Here we describe the peculiarities of the individual sources used to distill a global picture. We cite the original references of the archival data used in our analysis, as well as the main observational properties of the targets inferred from the visual inspection of the published maps.

Our descriptions of the high resolution H i properties of the XMPSs are based on the definition of several source parameters: the position angle of the largest H i extension, measured counterclockwise from the west (PAH i), the position angle of the largest optical extension, measured counterclockwise from the west, from the SDSS or DSS images (PAopt), the position angle of the H i velocity gradient, measured counterclockwise from the west (PAVG), the position angle of the H i velocity field (PAkin), the offset between the H i peak and/or the optical center/brightest star-forming knot (ΔD), and the offset between the H i velocity gradient or largest extension position angle and the optical largest extension position angle (Δθ).

References and survey/interferometer information (GMRT, VLA, THINGS—The H I Nearby Galaxy Survey, ACS—Advanced Camera for Surveys, ANGST—ACS Nearby Galaxy Survey Treasury) for the H i data are provided for each of the sources.

J0119-935 From Ekta & Chengalur (2010; their Figures 3 and 4), with the GMRT. The lower resolution (46″ × 32″) H i map shows a single-peaked “boomerang-type” northeast–southwest disk structure (PAH i ≈ 120°), with an extension to the south and to the north, the latter which connects to a clump of emission to the northwest. The orientation of the H i disk is roughly coincident with the position angle of the optical cometary emission (PAopt ≈ 115°). However, the center of the H i emission does not coincide with either the center of the optical disk, nor the bright star formation knot that leads the cometary structure in the northeast (ΔD ≤ 10″). In the central regions, the H i velocity gradient (PAVG ≈ 120°) follows the H i and optical morphology. However, in the outskirts, the H i velocity field displays distortions, with the mimicking of the “boomerang” shape observed in the H i morphology. The intermediate resolution (30″ × 20″) image shows a “Y-shaped” H i morphology, cradling the bright optical star formation knot toward the northeast, with the southern extension curving toward the East. The position angle at this resolution (PAH i ≈ 110°) is roughly coincident with the larger-scale H i and optical morphology.

UM 133 From Ekta & Chengalur (2010; their Figures 1 and 2), with the GMRT. The lower resolution (42″ × 36″) map of the H i gas displays a single-peaked northeast–southwest disk (PAH i ≈ 105°), with a small extension to the south and a larger extension to the east. The H i and optical coincide in terms of position angle and geometric (disk) center/H i peak. There is a less than 10″ distance between the H i peak and the bright star formation knot to the southeast, leading the cometary structure. In the central regions, the H i gas velocity gradient (PAVG ≈ 105°) is smooth and parallel to both the optical (PAopt ≈ 105°) and H i morphology, which is consistent with a rotating disc. However, distortions are seen in the outskirts, particularly toward the south and east, in the direction of the H i extensions. At an intermediate resolution (22″ × 17″), the H i morphology is “arrow-shaped,” pointing toward the northeast, and accompanying the overall optical structure. Similarly to the lower resolution images, extensions to the south and east are observed. The morphology and central velocity gradient on these scales match the larger-scale H i and optical morphology. Although in the central regions the velocity field is well-behaved, in the periphery there are clear asymmetries: the velocity gradient changes to the north-northeast, and large irregularities are detected to the south-southeast.

SBS 0335-052E and SBS 0335-052W From Ekta et al. (2009; their Figures 1, 4, and 5), with the GMRT. The low resolution (∼40″) map shows this interacting pair of XMP galaxies (ΔD ∼ 20 kpc), enveloped in a common H i structure (PAH i ≈ 175°), with each H i peak corresponding to a galaxy. At intermediate (∼20″) resolution, the individual single-peaked H i structures are distinguishable. The elongated disks are oriented along approximately the same direction (PAH i ≈ 145° for the eastern, and PAH i ≈ 150° for the western, component). SBS 0335-052W displays a small node of emission to the southwest. The H i peaks are slightly off-center (ΔΔD ≤ 10″) from the peaks of optical emission. In the case of SBS 0335-052E, the extended H i emission is approximately perpendicular to the northwest extension seen in the optical image (PAopt ≈ 45°). The velocity gradient in SBS 0335-052W changes from the center (approximately north–south) to the outskirts (northeast–southwest). For SBS 0335-052E, the velocity gradient is along the tidal tail (northeast–southwest), but deviates from a standard disk. High resolution (∼9″) observations show that SBS 0335-052W maintains the overall H i position angle seen at lower resolutions, with an extension to the northeast. The direction of the velocity gradient is approximately northwest–southeast. SBS 0335-052E reveals extended emission (PAH i ≈ 20°), roughly aligned with the optical cometary tail.

UGC 4305 (also known as Holmberg II, Arp 268, DDO 050 or VII Zw 223) From Walter et al. (2008; their Figure 13) and from the VLA THINGS. High resolution (6/95 × 6/05) H i maps show an almost symmetric spiral-like structure, the internal H i morphology is complex, displaying holes, clumps, and arms. The optical loop appears associated with the brighter H i spiral arm in the south, which encloses a prominent H i hole. The southern (fainter) arm extends as a tail to the southwest. The H i velocity gradient runs approximately north–south (PAVG ≈ 100°), within Δθ ∼ 15° of the optical position angle (PAopt ≈ 115°).

HS 0822+03542 From Chengalur et al. (2006; their Figures 1, 4, and 5), with the GMRT. The low resolution (42″ × 37″) map shows the XMP target along with its pair to the northeast, the low surface brightness galaxy SAO 0822+545, at a distance of D ∼ 11 kpc and a position angle of PA ≈ 125°. At this resolution, the H i gas is single-peaked, with an extension to the east-northeast. The velocity field (27″ × 23″) displays a distortion, with the velocity gradient northwest–southwest (PAVG ≈ 70°) near the center, aligned with the H i morphology (PAH i ≈ 70°), and approximately east–west (PAVG ≈ 170°), roughly perpendicular to the H i, toward the southeast. Intermediate and high resolution (17″ × 15″ and 13″ × 11″) images show a single-peaked, northwest–southeast disk...
(PA$_{HI}$ ≈ 70°), with an extension to the northwest-west, and a clump of emission to the northeast, the latter tracing the extension seen at lower resolution. The extension to the northwest-west appears to mimic the position angle of the optical cometary tail (PA$_{opt}$ ≈ 45°). There is an offset between the H I peak and the center of the optical disk, and a bright star formation knot to the southeast (ΔD ≲ 10 arcsec). At the highest resolution (7″ × 5″), the H I gas morphology resembles two almost vertical (PA$_{HI}$ ≈ 80°) “fingers,” pointing to the bright star formation knot, and peaking on either side. Overall, there is an offset of Δθ ≈ 30° between the optical and H I alignment.

**UGC 4459** (also known as DDO 053 or VII Zw 238) From Walter et al. (2008; their Figure 17), from VLA THINGS, and Begum et al. (2006; their Figure 4), with the GMRT. The H I map at intermediate resolution (29″ × 27″) shows a double-peaked quasi-symmetric spherical structure, with a small extension to the northeast. The two H I peaks are roughly coincident with the opposite ends of the optical main disk, with an H I depression in between. There is slight H I enhancement associated with the secondary optical disk. The overall position angle of the H I emission (PA$_{HI}$ ≈ 150°) is approximately perpendicular to the optical emission (PA$_{opt}$ ≈ 55°). The velocity gradient direction (PA$_{VG}$ ≈ 45°) is relatively well-aligned with the optical morphology. The velocity gradient is not uniform, with the field displaying an asymmetry, weighted toward the southeast. Similarly to the intermediate resolution images, the high resolution (6′34″ × 5′57″) H I maps show two high-density H I clumps, with a central depressed region, embedded in an H I halo, with faint eastern–northeastern emission. The H I emission associated with the fainter optical disk is more apparent. On these scales, the velocity gradient direction is roughly aligned with the optical morphology and the larger-scale velocity gradient, and mimics what occurs at low resolution: there are deviations toward the southeast.

**UGC 4483** (also known as Mrk 0090 or SBS 0826+528) From Ott et al. (2012; their Figure 7), from the VLA ANGST, and Lelli et al. (2012b; their Figures 1 and 2) and Lelli et al. (2014a, 2014b; their Figures 1, C.11, and 1, 2), with the VLA. The intermediate resolution (20″ × 20″) H I map shows almost vertical (PA$_{HI}$ ≈ 80°) “arrow-shaped” emission, where the head of the arrow spatially coincides with the bright star formation knot to the north, heading the cometary optical morphology. There is also extended H I emission to the south and northwest. The central H I morphology matches well the observed “X-shaped” and overall optical morphology (PA$_{opt}$ ≈ 80°). The kinematical axis is vertical (PA$_{kin}$ ≈ 90°), roughly matching the position angle of the brighter arm (PA$_{opt}$ ≈ 95°) associated with the “X-shaped” optical morphology. The velocity field can be modeled by a rotating disk, possibly with a radial component. High resolution (10″ × 10″) H I observations mimic the larger-scale arrow-shape emission, but two H I peaks are resolved, the brightest of which is elongated to the southeast and spatially coincides with the bright optical star formation knot. There is extended emission also to the south and east. On these scales, the H I major axis (PA$_{HI}$ ≈ 60°) appears to follow in the direction of the fainter “arm” associated with the “X-shaped” optical morphology (PA$_{opt}$ ≈ 60°). The H I kinematical axis is vertical (PA$_{kin}$ ≈ 90°), and matched to the larger-scale velocity gradient. The highest resolution (~6″) H I image is similar to its larger-scale counterparts: the overall morphology is arrow-shaped (PA$_{HI}$ ≈ 80°), with two resolved H I peaks, the brightest of which is positionally coincident with the bright star-forming knot. On these scales, the velocity gradient (PA$_{VG}$ ≈ 120°) is misaligned relative to the H I and optical (PA$_{opt}$ ≈ 80°) major axes. The velocity field displays asymmetries and distortions along the axis.

**IZw 18** (also known as UGCA 166, Mrk 0116, or SBS 0930+554) From Lelli et al. (2012a; their Figures 2, 3, and 4) and Lelli et al. (2014a, 2014b; their Figures C.16 and 1, 2), with the VLA. The intermediate resolution (20″ × 20″) H I image shows single-peaked “triangle-shaped” emission (PA$_{HI}$ ≈ 45°), with a southeast extension that curves due south, along D ∼ 14 kpc. The main body of the H I emission is aligned with the optical morphology (PA$_{opt}$ ≈ 45°). The peak of the H I coincides with the position of the brightest (northwest) star formation knot in the optical image. There is small extended emission to the northeast, north and northwest. The latter emission is likely associated with the companion galaxy, IZw 18 C, with which it is interacting, at a distance of D ∼ 18 kpc. The kinematical axis (PA$_{kin}$ ≈ 50°) is roughly aligned with both the (main) H I and optical emission. The large southern extension is at an almost constant velocity. At high resolution (5″ × 5″), the H I emission is resolved into two peaks, positionally coincident with the two brightest star formation knots in the optical image. There is also a halo of extended emission to the northeast, engulfing the interacting companion, IZw 18 C. The velocity field (PA$_{kin}$ ≈ 55°) can be modeled by a rotating disk plus radial motion, with signs of distortion in the direction of IZw 18 C. At even higher resolution (2″ × 2″), there is peaked H I emission extended to the south/seast, in an inverted “V-shaped” morphology, and extended emission to the northwest, in the direction of IZw 18 C.

**J0956+2849** (also known as UGC 4350 or DDO 068) From Ekta et al. (2008; their Figures 1 and 3), with the GMRT. The low resolution (39″ × 35″) H I map shows a double-peaked inverted “s” morphology, extending to the north-northwest, and to the southwest; the southwest extension coincides with the southwestern optical tail. The main H I peak is slightly off-center from the optical peak (∆D ≲ 20″), while the secondary H I peak coincides with the bright star formation regions seen in the northern optical extension. The overall H I morphology (PA$_{HI}$ ≈ 107°) is slightly misaligned from the optical structure (PA$_{opt}$ ≈ 115°) and velocity gradient (PA$_{VG}$ ≈ 115°). At this resolution, the velocity field is consistent with a rotating disk, with some asymmetry between the northern and southern field lines. The intermediate (27″ × 22″) and high resolution (12″ × 10″) maps, although maintaining the overall H I morphology (PA$_{HI}$ ≈ 107°), show more detailed structure. The H I emission shows two “spiral arm-like” structures, one curving north–east–south and the other curving south–west–north. Ekta et al. (2008) interpreted the unusual H I “spiral” structures as tidal tails from a merger remnant.

**Leo A** (also known as Leo III, UGC 5364, or DDO 069) From Begum et al. (2006, their Figure 9), with the VLA. The low resolution (~78″) H I map shows unequal double-peaked H I emission, almost horizontal (PA$_{HI}$ ≈ 108°) disk morphology, which is coincident with the optical position angle (PA$_{opt}$ ≈ 108°). There are faint extensions to the north and south.
Sixtans B (also known as UGC 5373 or DDO 070) From Ott et al. (2012, their Figure 10), from the VLA ANGST. The high resolution (~6") HI map shows a complex, quasi-spherical, spiral-like morphology, with HI clumps and holes. The regions of more enhanced HI emission appear to lie mainly above the optical disk and on the southeast side, in an inverted “C-shape,” so that the internal HI morphology is roughly aligned with the optical disk (PA_{HI} ≈ PA_{opt} ≈ 25°). The direction of the velocity gradient (PA_{V0} ≈ 130°) is virtually perpendicular to the (internal) HI and optical morphology.

Sixtans A (also known as UGCA 205 or DDO 075) From Ott et al. (2012; their Figure 13), from the VLA ANGST. The high resolution (~6") H image shows an elongated (PA_{HI} ≈ 135°) disk-like structure, with HI clumps and gaps. The HI morphology is approximately perpendicular to the optical axis (PA_{opt} ≈ 45°). The HI is enhanced on either side of the optical disk, roughly positionally coincident with the brightest star formation knots, with opposite extensions to the north and south. The velocity gradient direction (PA_{V0} ≈ 150°) is slightly misaligned with the HI morphology, but roughly perpendicular to the optical disk.

UGC 6456 (also known as VII Zw 403) From Thuan et al. (2004; their Figures 17, 18, and 20), and Lelli et al. (2014a, 2014b; their Figures 1, C.12, and 1, 2), from the VLA. The intermediate resolution (20° × 20", 212° × 145", 172° × 11", and 15° × 15") HI maps show double-peaked disk emission (PA_{HI} ≈ 75°), extended to the northwest, south and west. The HI emission does not align with the main optical emission (PA_{opt} ≈ 115°), but does align with the faint extended emission (PA_{opt} ≈ 75°). The main HI peak coincides, not with the center of the optical disk, but with the brightest star forming regions to the south in the optical image. The velocity field is disturbed, and can be modeled by a combination of rotation and radial motions. The kinematical axis (PA_{kin} ≈ 90°) is vertical, with the rotation occurring along the HI major axis.

SBS 1129+576 From Eta et al. (2006; their Figures 1, 3, and 6), with the GMRT. The low resolution (42° × 40") HI map shows the XMP target, along with its companion galaxy, SBS 1129+577, D ≈ 27 kpc to the north, and the dwarf galaxy SDSS J113227.68+572142 to the southeast. The image signals the interaction of the SBS 1129+567/577 pair, by way of an H I bridge connecting both galaxies, and a common HI envelope. There is also a small tail of emission to the northeast and southwest of the XMP. At this resolution, the position angle of the HI emission associated with the XMP target is PA ≈ 75°, which is roughly coincident with the direction of the velocity gradient (PA_{V0} ≈ 70°). The velocity field is fairly ordered (solid-body rotation) in the central region and also in the bridge, consistent with a prograde merger. The high resolution (6'' × 14'') map shows a northwest–southeast disk (PA_{HI} ≈ 70°), in good agreement with the optical axis (PA_{opt} ≈ 75°). The disk displays small extensions to the south, east and west, similar to what is seen at lower resolution. The position of the HI peak encompasses both the optical disk center and the bright knot to the southeast. At high resolution (8'' × 7''), the HI peak is resolved into two high density regions, each positionally coincident with the optical disk center and the bright star formation knot. Similarly to the low resolution image, extended emission to the south, east and west is detected. The somewhat curved tips of the HI disk may suggest a warp. The HI position angle on small scales (PA_{HI} ≈ 70°) is roughly in agreement with that on intermediate–large scales, with the direction of the velocity gradient, and with the optical disk.

UGC 292 (also known as NGC 128) From Young et al. (2003; their Figure 2), with the VLA, and Ott et al. (2012; their Figure 22), from the VLA ANGST. Intermediate resolution (177" × 174" and 142" × 139") HI maps show triple-peaked, “boomerang-shaped” HI emission along an almost horizontal axis (PA_{HI} ≈ 175°). The internal HI inverted “V-shape” structure mimics what is observed in the optical (PA_{opt} ≈ 165°). Indeed, the HI peaks are positionally coincident with the ends and center of the optical disk, where bright star formation knots can be found. The vertical gradient direction (PA_{V0} ≈ 145°) is misaligned by about 20° from the overall HI and optical emission, but is roughly aligned with the southwest “boomerang” optical/HI arm. The velocity field displays an asymmetry in the periphery. The high resolution (~6") HI spatial distribution and velocity field is a scaled-down version of the lower resolution observations.

GR 8 (also known as DDO 155, UGC 8091, or VIII Zw 222) From Young et al. (2003; their Figure 3) and Begum & Chengalur (2003; their Figures 2, 3, and 4), with the VLA, Begum et al. (2006; their Figures 9, 12, and 13), with the GMRT, and Ott et al. (2012; their Figure 23), from the VLA ANGST. At low and intermediate resolution (30" × 30" and 25" × 25"), the overall HI emission is triple-peaked, enclosed in a “cross-shaped” halo (PA_{HI} ≈ 165°), where the central triple-peak emission is “V-shaped.” The kinematical axis (PA_{kin} ≈ 80°) is misaligned with both the HI and the optical disk emission (PA_{opt} ≈ 130°). The velocity field can be modeled by a combination of circular plus radial motions of the gas, showing distortions in the outskirts. Intermediate resolution (18" × 18" and 14" × 14") and high resolution (~6" and 4" × 3") HI images mimic the triple-peaked “V-shaped” structure (PA_{HI} ≈ 165°) seen at lower resolution. These peaks are slightly misaligned relative to the position of the three brighter star-forming regions in the optical disk.

SBS 1415+437 From Lelli et al. (2014a, 2014b; their Figures C.18, and 1, 2), with the VLA. The intermediate resolution (20" × 20") HI map shows a single-peaked northeast–southwest (PA_{HI} ≈ 115°) disk, extended to the north, and with smaller extensions to the south, east and west. The HI peak is positionally coincident, not with the center of the optical disk, but with the southern bright star formation knot that heads the cometary structure, while the cometary tail is mirrored in the northeastern extension. High resolution (10" × 10") HI observations show a similar morphology to the intermediate resolution image, but where the extended south, east and west emission is now resolved into a web of small tails and filaments. The HI emission at intermediate–high resolution scales is roughly aligned with the optical disk (PA_{opt} ≈ 120°) and the kinematical axis (PA_{kin} ≈ 115°). The velocity field is ordered (rotation) only in the center, with the outskirts displaying lopsidedness.

Sag Dig From Begum et al. (2006; their Figure 9), with the GMRT, and Beccari et al. (2014; their Figures 12 and 13), with the VLA. The low resolution (~67") HI map shows double-peaked quasi-spherical ring-like emission, with an off-center
H I depression (\(\Delta D \lesssim 1\%\)). The brightest H I peak roughly coincides with the bright star formation knots to the east, seen on the optical image (PA_{opt} \approx 170\%). At intermediate resolution (30\% \times 30\%), the ring-like structure becomes more apparent, with multiple H I clumps and a large off-center H I hole. The velocity field displays no sign of ordered rotation. Beccari et al. (2014) hypothesized that this source could be the result of a merger with another dwarf.

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