Search for new very low metallicity galaxies in the Local Universe, discovery of their diversity, and speculations on its origin

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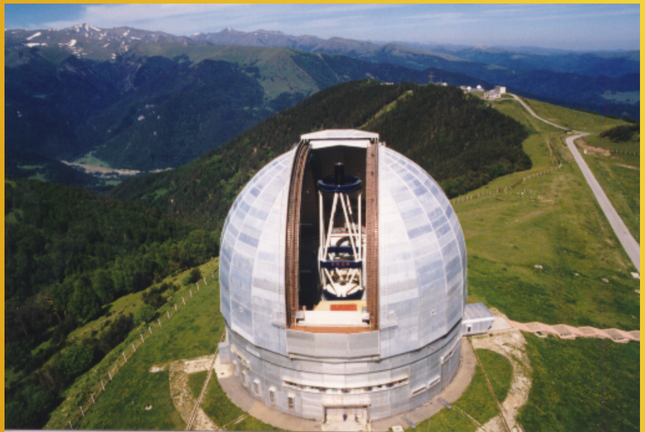
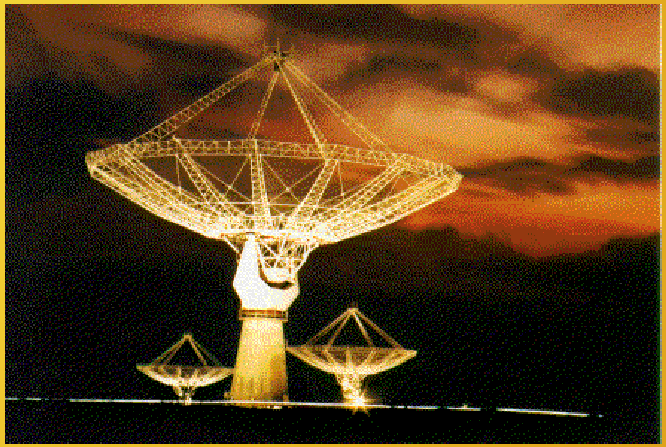
Diversity of the Local Universe,

Nizhnij Arkhyz, Russia





Outline

- **Introduction and some definitions**
- **Overview. Early results. Metal-poor objects and Very Young Galaxies. Current goal: check possible diversity of XMP dwarfs**
- **eXtremely Metal-Poor (XMP) galaxies: status update in the last decade**
- **On-going project to search for new Nearby Void XMP dwarfs**
- **Candidate selection and follow-up spectroscopy**
- **Current sample of known XMP (Z < Zo/30) objects**
- **Diversity and tentative types of XMP galaxies**
- **Speculations on XMP galaxy origin and evolution**
- **Nearest prospects from observational and theoretical perspectives**

Introduction and some definitions

- The subject of the talk is the **eXtremely Metal-Poor (XMP**), that is (late-type dwarf) galaxies with **Zo/50 < Z < Zo/30.**

Zo - metallicity of the Sun, M("metals")/M_tot~0.017 (Asplund+2009).

- We deal with the gas metallicity measured in HII regions excited by massive stars of their current/recent SF episodes.
- We use Oxygen abundance O/H as a substitute of metallicity.

The adopted value **12+log(O/H)(sun)=8.69** (Asplund+2009).

- We examine the **diversity of the lowest metallicity dwarfs** with **O/H(gas) of 12+log(O/H)=[6.98-7.19] (or Z=Zo/50-Zo/30)**

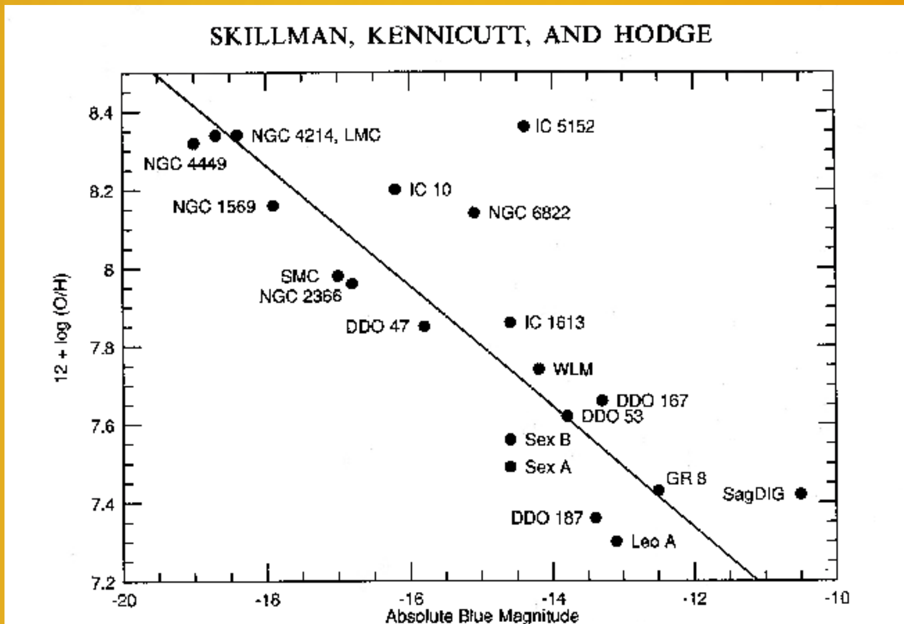
Overview. I. Early results.

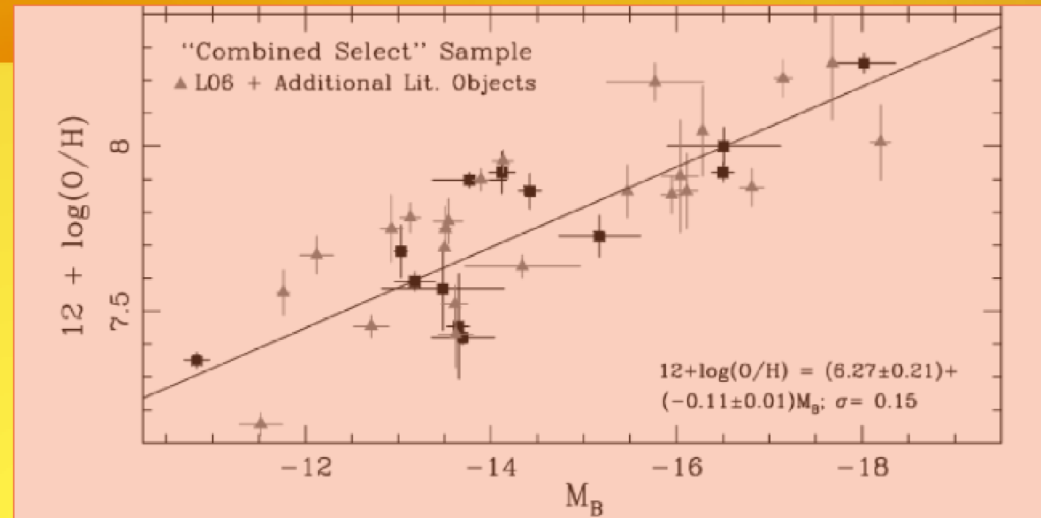
- Discovery of the nearby unusual blue compact galaxy (BCG) **IZw18 with Z(gas)~Zo/30 (Searle, Sargent, 1972)** at D~15 Mpc motivated interest to the issue of **young unevolved** galaxies in the Local Universe. Possible nice local probes of processes in low-Z gas, SF and massive stars in the “early” Universe, and primordial Helium.
- **SBS0335-052 E,W with close Z(gas)** discovered in 1989-1997 (**Izotov+1989** and follow-ups).
- Despite to numerous debates, the issue of the **existence of "young" galaxies** in the Local Universe still **have not settled and partly transformed to the area of definitions**.
- **Kunth & Ostlin (2000**, review) defined **metal-deficient** galaxies as those with

Z(gas) < Zo/10. Counted to that moment ~30 such objects.

- It is well known that **Z(gas) in dwarf galaxies falls systematically with luminosity** or **mass** (Lequeux+1979, Skillman+1989, Garnett, 2002; and more recently Berg+2012). **Some galaxies appear low-Z** (Zo/20-Zo/10) just **because they follow this trend and are small.** The underlying **processes behind this trend** are basically the interplay of:
- the reduced **efficiency of SF in lower mass galaxies (“downsizing”)** and
- the elevated **metal loss in** low gravitational potential of **small mass dwarfs due to SN energy release** in course of SF episodes.
- There are **several additional factors affecting** this **trend (interactions, global environment)** and lifting the scatter around it.

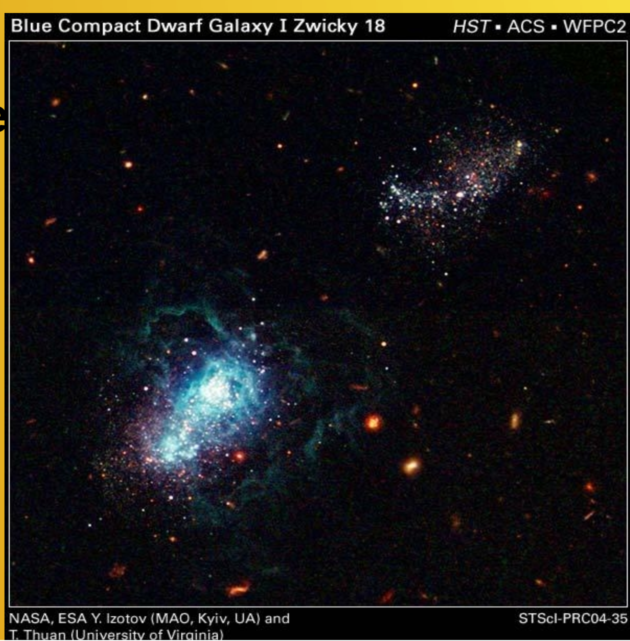
General trend of Z(gas) vs Luminosity. Two prototype XMP BCGs: IZw18 + IZw18C and SBS0335-052 E,W

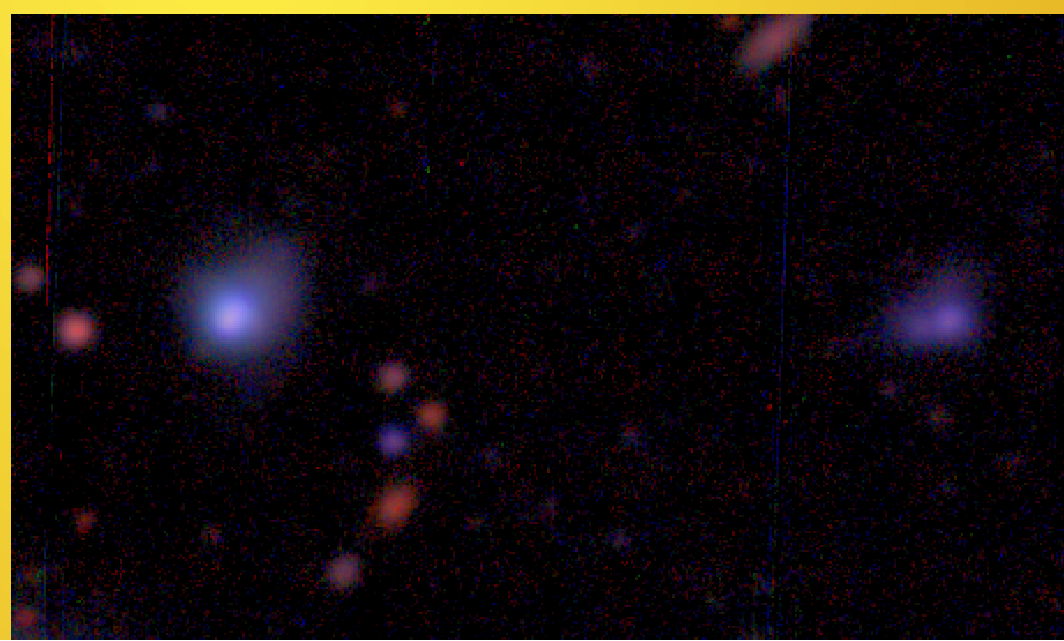




Berg+2012

HST image



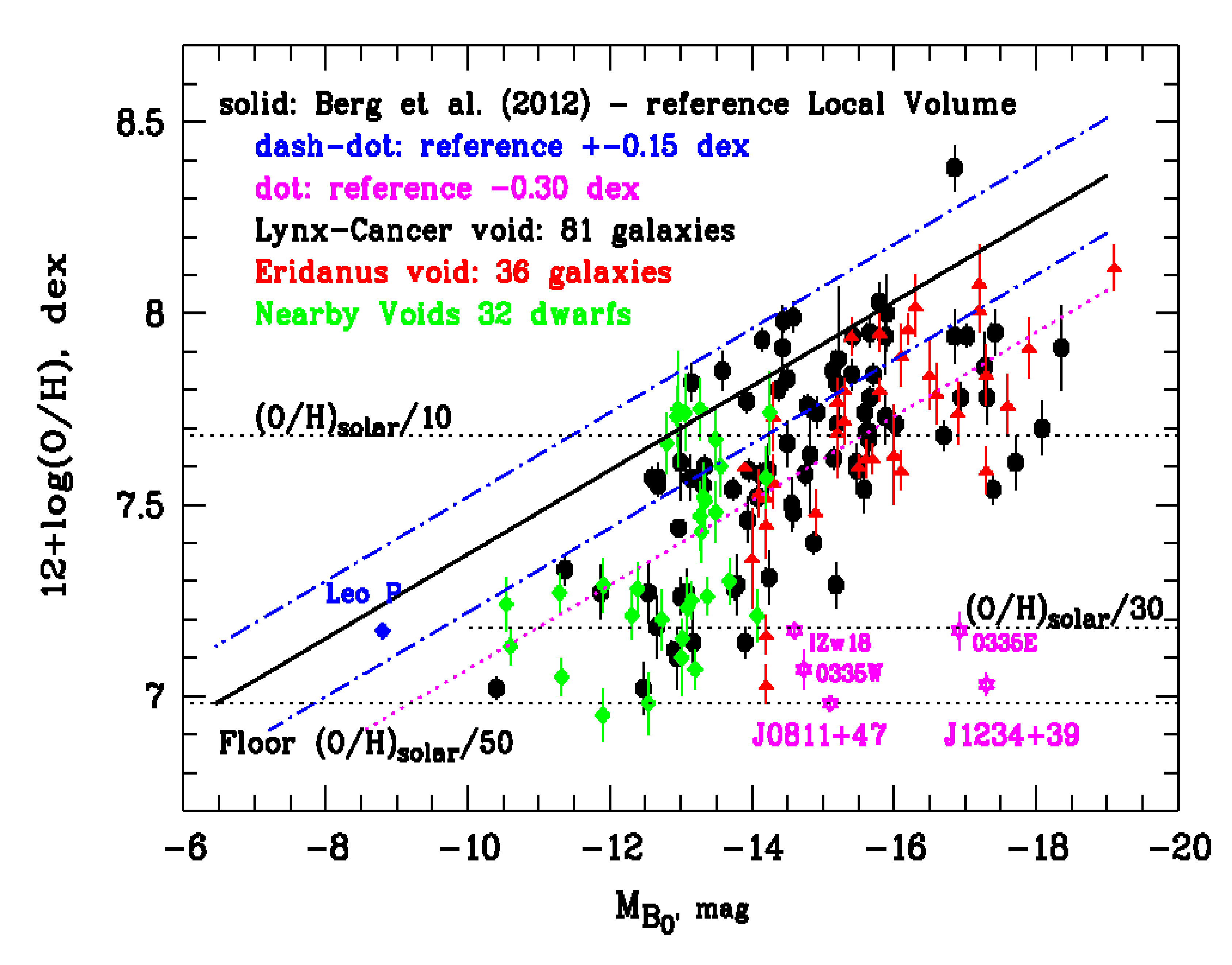


BTA image

Overview. II. Nowadays progress and Very Young Galaxies

- During the last decade, the number of low-Z (Z < Zo/10) galaxies grown to about a half-thousand, mainly thanks to searches among SDSS emission-line objects. Also part of such galaxies were found among new ALFALFA HI-bearing objects, as well as by photometric selection among SDSS objects and in course of systematic studies of galaxies in nearby voids.
- A certain part of them appear **low-Z on a relatively short time scale** (~50-100 Myr) due to mixing of gas in HII regions of the current star-burst with the **infalling IGM gas with pregalactic Z (<~Zo/50)** (e.g., Sanchez Almeida+2014, 2017, Ceverino+2016).
- However, the **XMP objects, with Z <~ Zo/30 (as for IZw18), remain extremely rare, comprising of two dozen** overall. Besides a dozen new XMP found via SDSS spectra (Izotov+2009,2012,2017,2019) and a couple of ALFALFA-SHIELD dwarfs (Skillman+2013, Hirschauer+2016), around 10 XMPs are found as nearby void dwarfs by our team (Pustilnik+ 2005,2010,2016,2019 - submitted).
- The majority of **void XMPs** show unusual properties: **M*/M(bary)~0.01-0.03**; **blue** colours of **outer parts**, implying **ages** of the main **oldest** stellar **population** of **< 1-3 Gyr**, very low O/H(gas), **reduced by 2-5 times** with respect of the Local Volume **Reference relation "O/H vs MB"** of Berg+2012.
- In addition, the **unusual XMP dwarfs attract more attention since they seem to be the best proxies of Very Young Galaxies** (VYG). **VYGs** are defined as galaxies formed the majority of their stars within the last ~1 Gyr. **Tweed+2018 simulations** predict the existence of such objects in the local Universe. Their fraction in models crucially depends on DM type (Cold vs Warm), hence their **statistics** can serve **as** an interesting **cosmological test.** Therefore, it is actual to study XMP objects in more detail, and in particular, to **examine the possible diversity of XMP galaxies as a group.**

log(O/H) vs MB for all available nearby void galaxies along with Reference Relation for Local Volume from Berg+2012



On-going project to search for XMP dwarfs in nearby voids

- A dozen of nearby XMP dwarfs are found thanks to dedicated search for and study of void galaxies.
- Brief summary of the on-going project based on the Nearby Voids Galaxy sample of ~1350 galaxies from Pustilnik, Tepliakova, Makarov (2019).

25 Nearby Voids and 3D view (in super-gal.coordinates) of the Local Void (Oph-Sgr-Cap) and Cnr-CMi-Hyd void

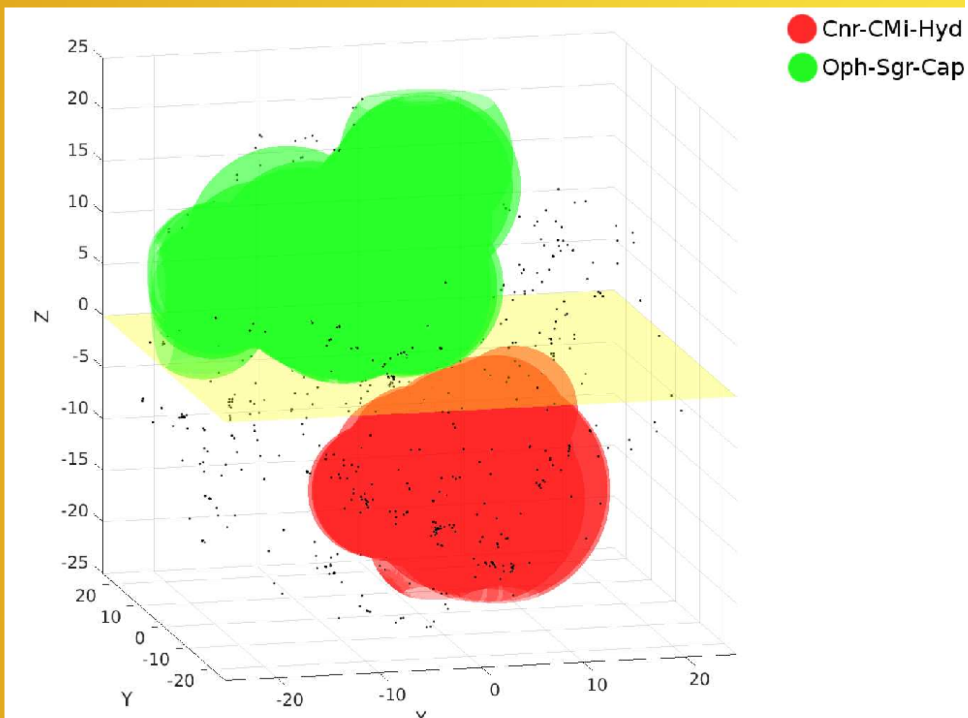
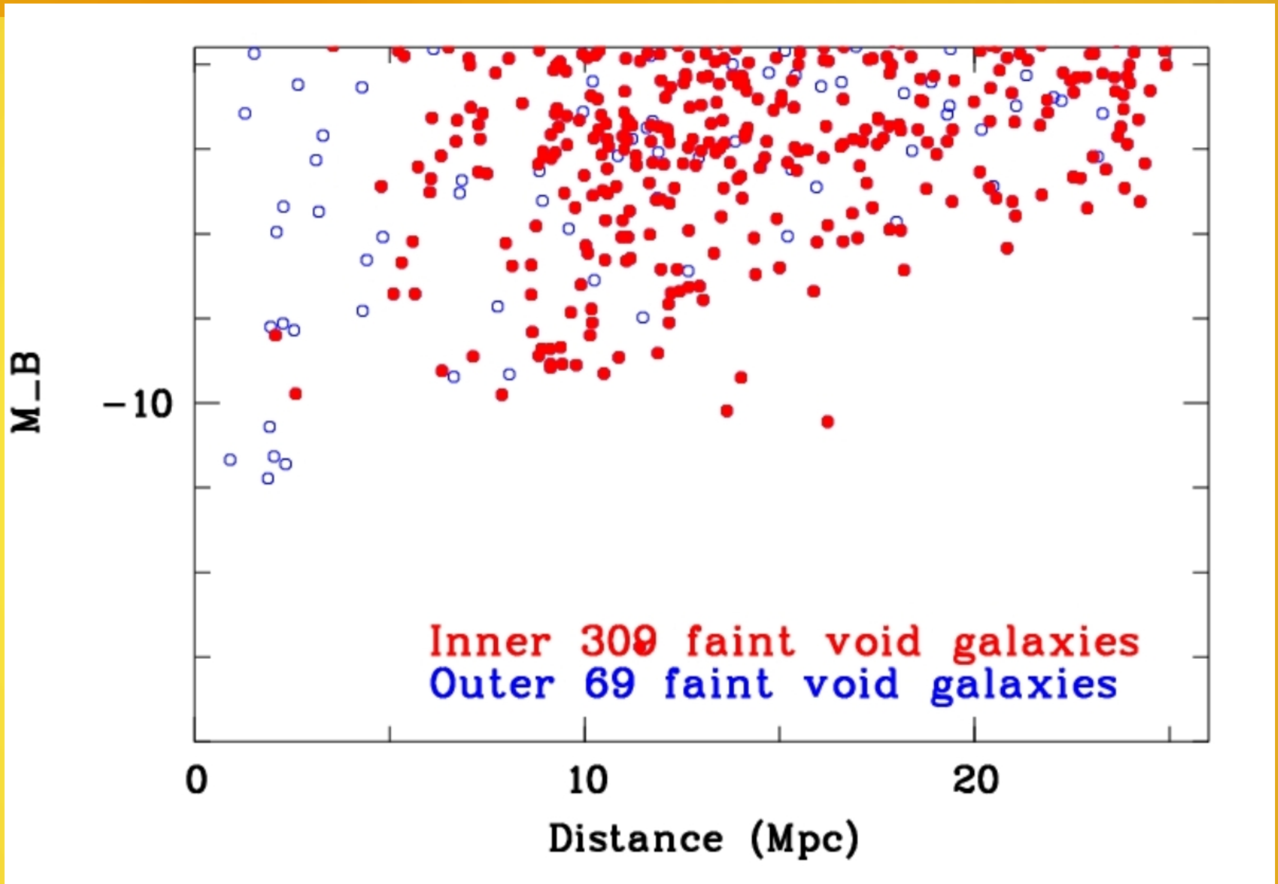


Table 1. Main parameters of nearby voids

#	Void name	RA_c hours	Dec_c degr	$Dist_c$ Mpc	Max.ext. ΔX,ΔY,ΔZ Mpc	Nu. orig. sphere	Nu. joined sphere	Tot. void gals	Inner void gals
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	Cas-And	00.7	+53	19.0	19,19,23	13	5	19	15
2	Tuc	00.9	–64	11.2	14,14,14	5	1	56	44
3	Cet-Scu-Psc	01.3	–02	15.2	33,17,29	40	14	108	85
4	Pho	01.4	–54	18.0	17,19,18	31	6	80	66
5	Tau	03.8	+17	18.8	24,27,21	17	7	53	46
6	Per	04.0	+52	19.7	14,14,13	2	1	4	3
7	Eri-Ori	05.1	–07	18.5	20,18,17	5	2	41	30
8	Ori-Tau	05.4	+15.2	07.5	18,14,14	11	3	46	36
9	Aur	05.8	+38	13.5	23,22,21	14	4	36	34
10	Lep	05.85	–17	06.3	13,13,13	3	1	43	32
11	Mon	06.4	–07	20.2	19,15,16	9	3	7	2
12	Cnr-CMi-Hyd	08.5	+10	17.5	29,25,23	40	14	129	106
13	Vel	09.5	–50	19.0	20,27,21	29	7	76	59
14	Hyd	09.8	–15.2	19.2	18,14,17	8	3	22	15
15	Cen-Cir	14.4	–65	21.0	15,14,15	4	1	20	14
16	UMa	14.8	+59	21.0	15,16,13	6	2	82	73
17	Vir-Boo	14.8	+07	10.2	14,14,15	5	2	20	12
18	Boo	15.3	+27	19.4	20,24,26	11	4	49	33
19	Lib	15.4	–26.5	18.3	19,21,24	23	7	40	31
20	Her	16.6	+20	13.5	21,22,25	28	8	118	97
21	Oph-Sgr-Cap	18.5	–18	13.0	37,30,35	68	23	121	89
22	Dra-Cep	20.4	+71.1	13.9	21,21,17	16	5	50	44
23	Cyg	20.6	+36.3	19.3	22,23,28	7	3	20	18
24	Pav-Oct	20.7	–73.1	15.7	23,20,18	19	5	36	30
25	Aqu	22.7	–02.5	15.5	20,22,24	33	9	80	72

Least luminous dwarfs in NVG sample

One of the goals of forming of the Nearby Void galaxy sample was a substantial increase of amount of void low-luminosity dwarfs. In this figure we show NV galaxy distribution for range of MB ~> -14.2 along the distance from us.



XMP candidate selection and follow-up spectroscopy

1. **In the unbiased study of ~100 galaxies residing in the nearby void Lynx-Cancer (Pustilnik+2017 and references) we found several unusual dwarfs, mostly LSB XMPs, blue and very gas-rich, resembling the predicted in simulations VYGs (Tweed+2018).**

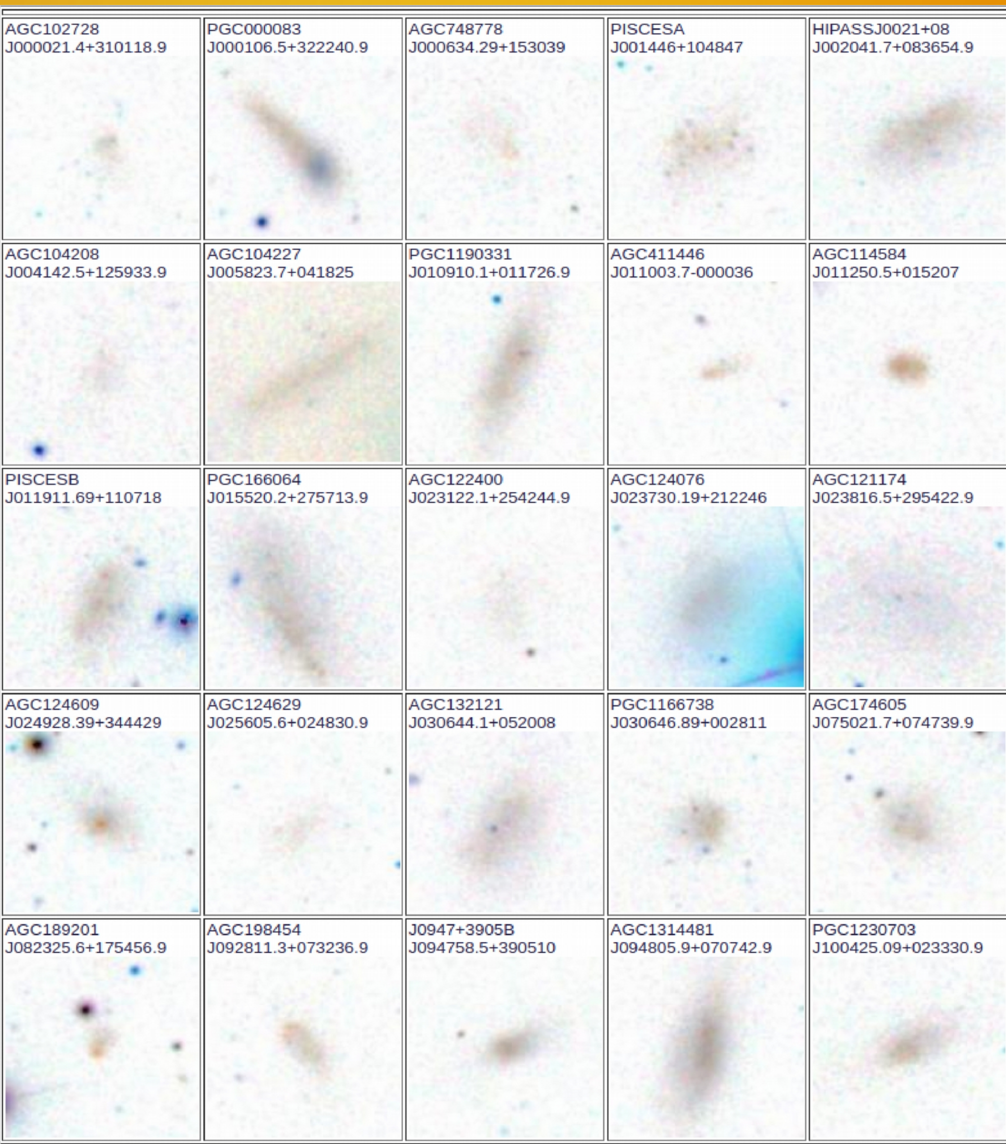
2. We consider these unusual XMP dwarfs as prototypes and use their observational properties to find similar objects in the NVG sample.

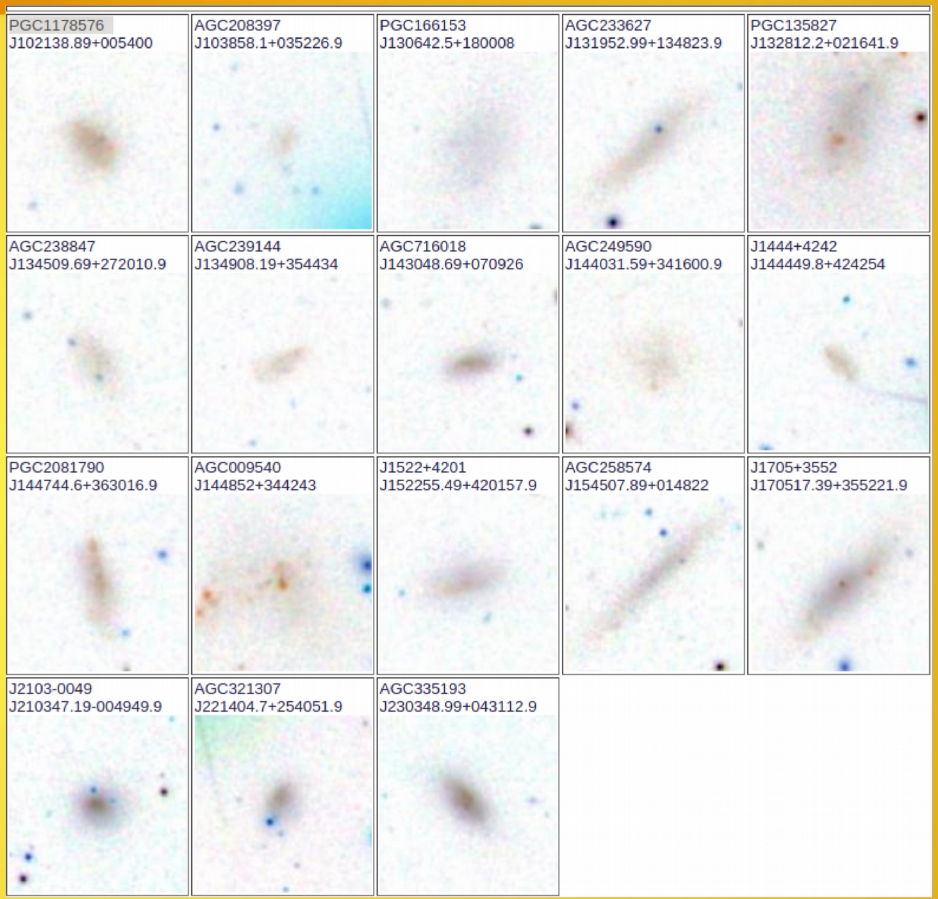
3. We select about 60 canditates from NVG sample for the follow-up spectroscopy at the SAO 6-m telescope BTA (SCORPIO) and South African 11-m telescope SALT (RSS). Altogether, spectra are obtained for 36 objects.

Six new XMP dwarfs with **Z~Zo/50-Zo/30 are found, and about 10 more – with**

Z=Zo/30-Zo/20.

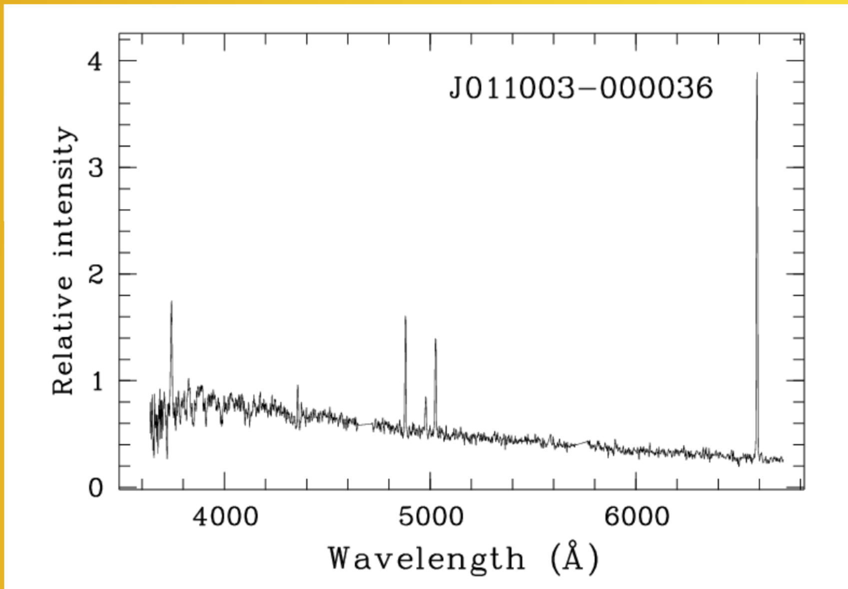
Finding charts of selected XMP candidates from SDSS colour images (side ~50“). Inverted colours to better see LSB features

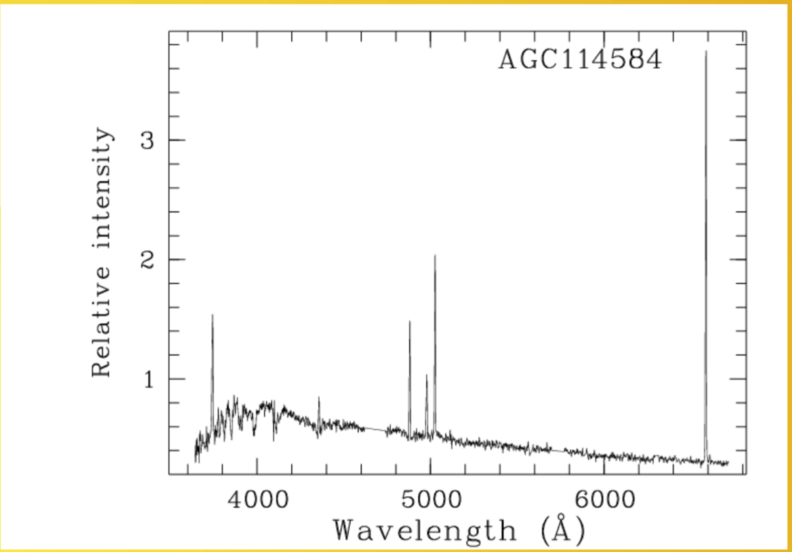


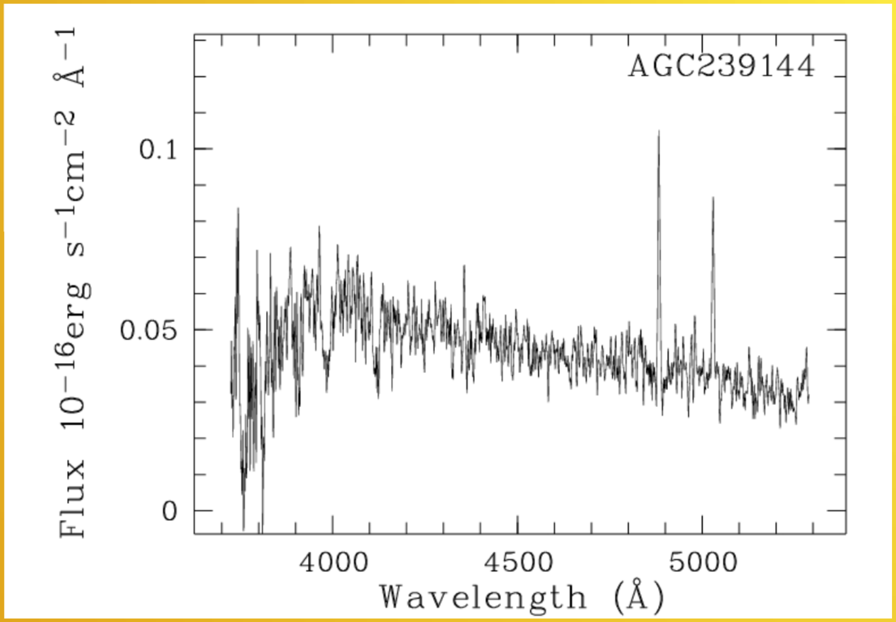


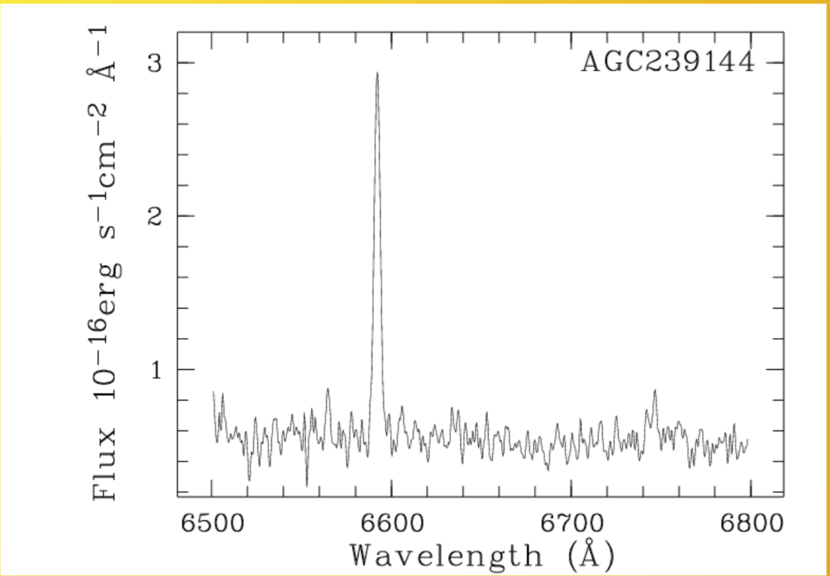
Spectra of new XMP dwarfs.

J0110-0000 (O/H=7.05), AGC114584 (O/H=7.15), AGC239144 (O/H~7.0). O/H is estimated via a new Strong Lines method by Izotov et al. (2019) nicely suited for the lowest metallicity HII regions (12+log(O/H) < 7.4)





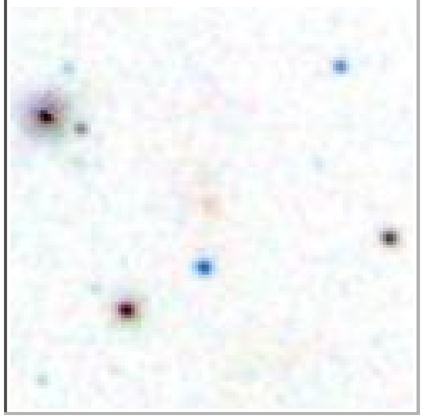




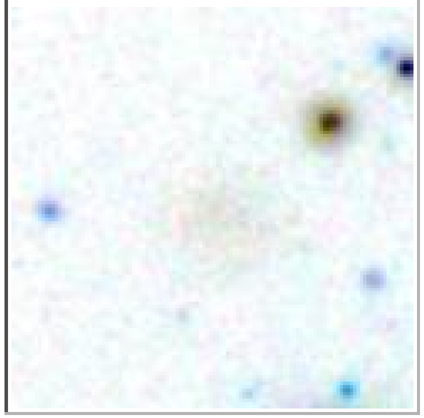
Part of the current sample of Nearby Void XMP galaxies. SDSS images in inverse colours - to see their LSB nature.

J0015+0104
J001521.2+010429.9

J0706+3020
J070623.39+302051



J0723+3622
J072313.5+362213



AGC194054
J092610.09+334311.9

AGC198691
J094332.39+332657.9

AGC411446
J011003.7-000036

AGC114584
J011250.6+015207.9

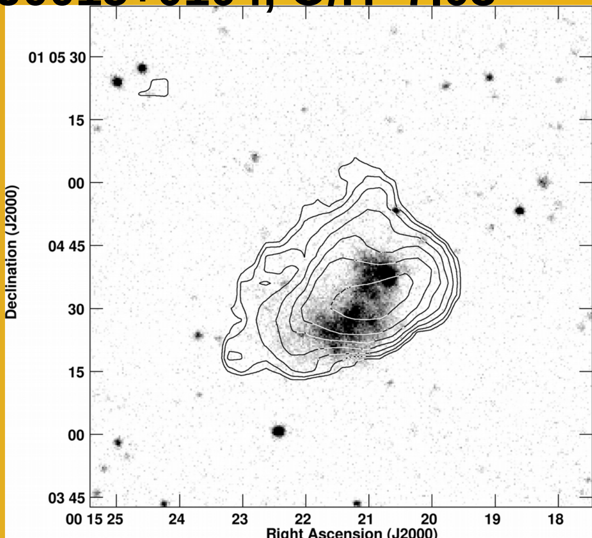
AGC124629
J025605.6+024830.9

AGC208397
J103858.1+035226.9

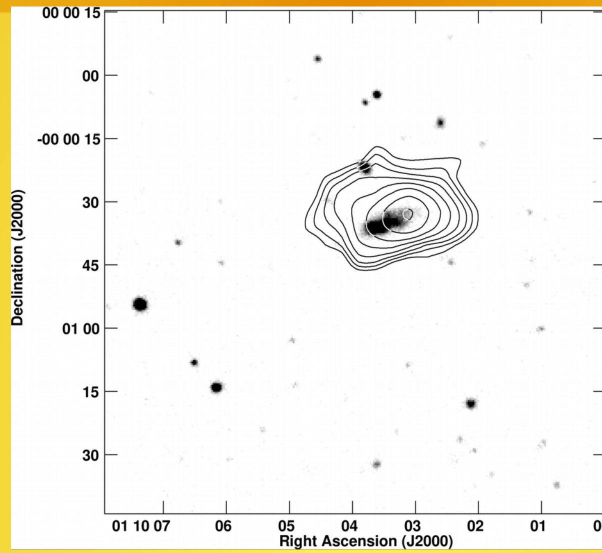
AGC239144
J134908.19+354434

<u>Isolated</u> void gas-rich XMP LSB dwarfs (in preparation) through the GMRT HI window. (O/H means 12+log(O/H)). All galaxies display disturbed HI features of unclear nature.

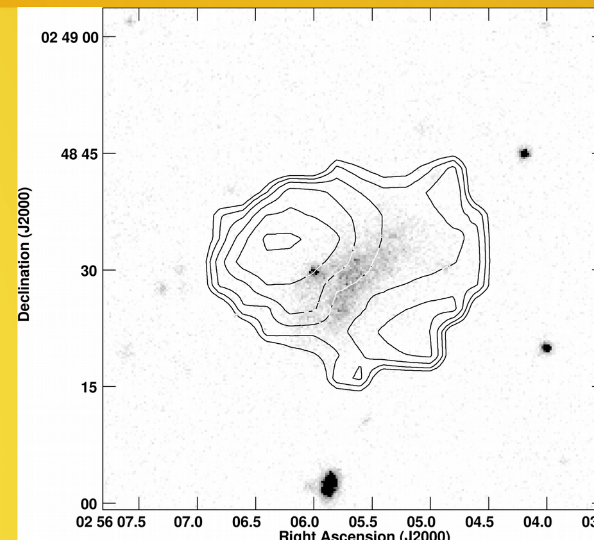
J0015+0104, O/H=7.03



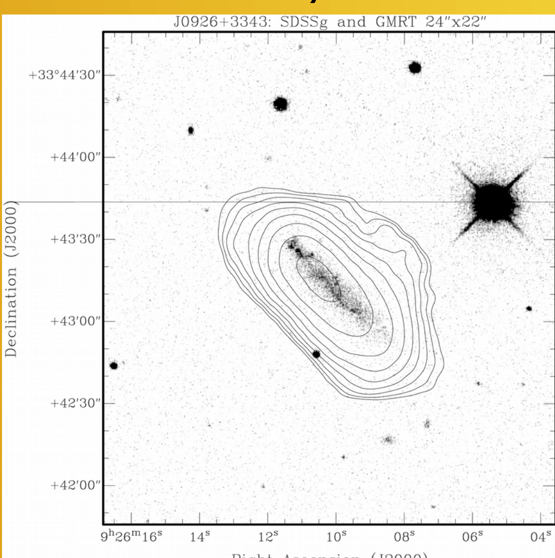
J0110-0000, O/H=7.05



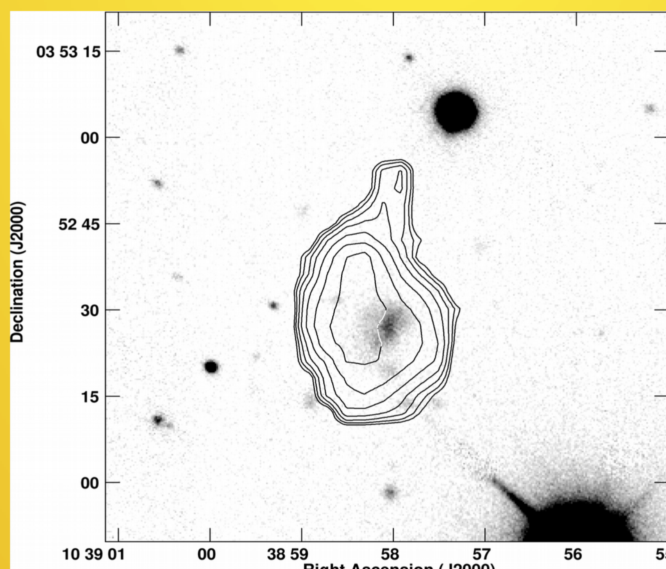
J0256+0248,O/H=6.95



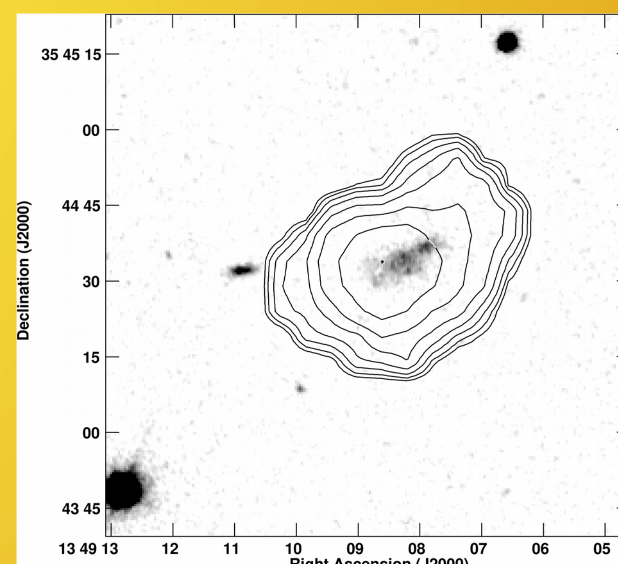
J0926+3343, O/H=7.12



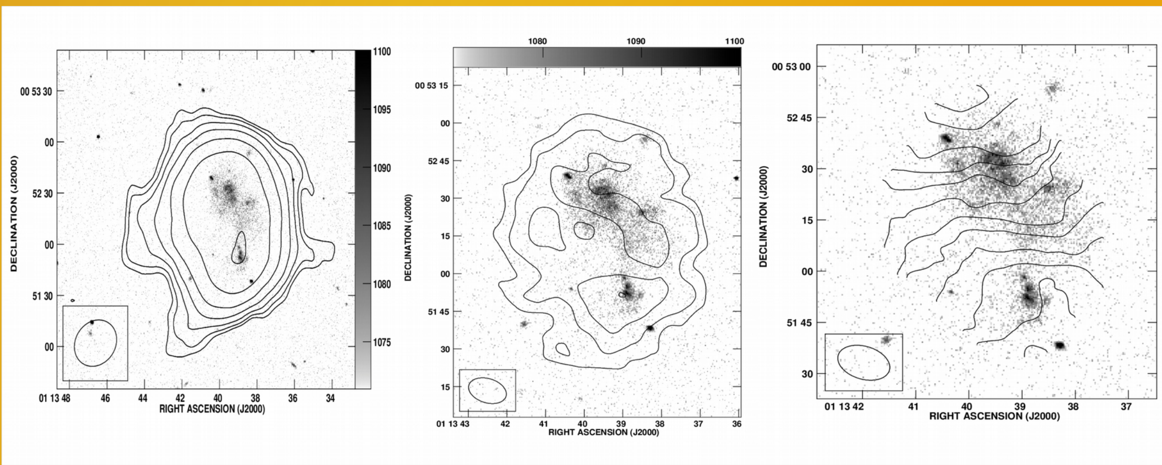
J1038+0352, O/H=7.13



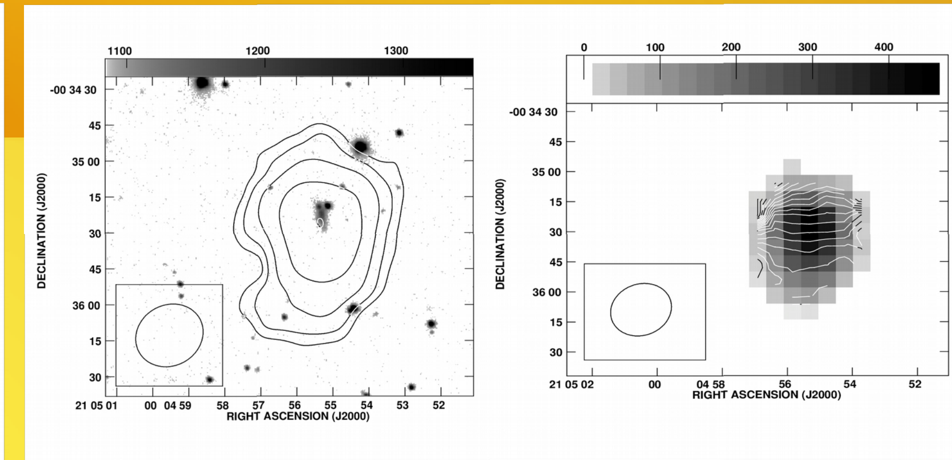
J1349+3544, O/H=6.98



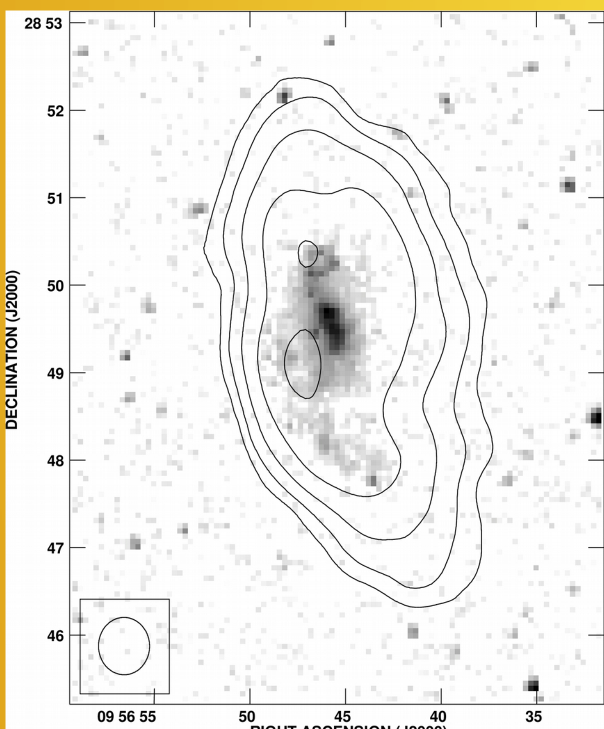
Interacting or merging void XMP galaxies (J2104-0035, UGC772 and DDO68) and SBS 0335-052



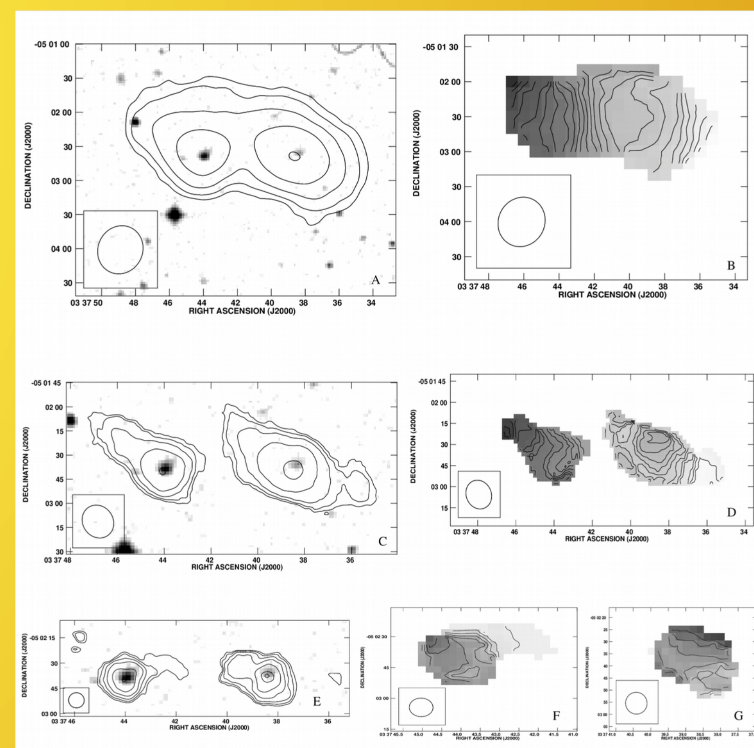
UGC772



SDSS J2104-0035



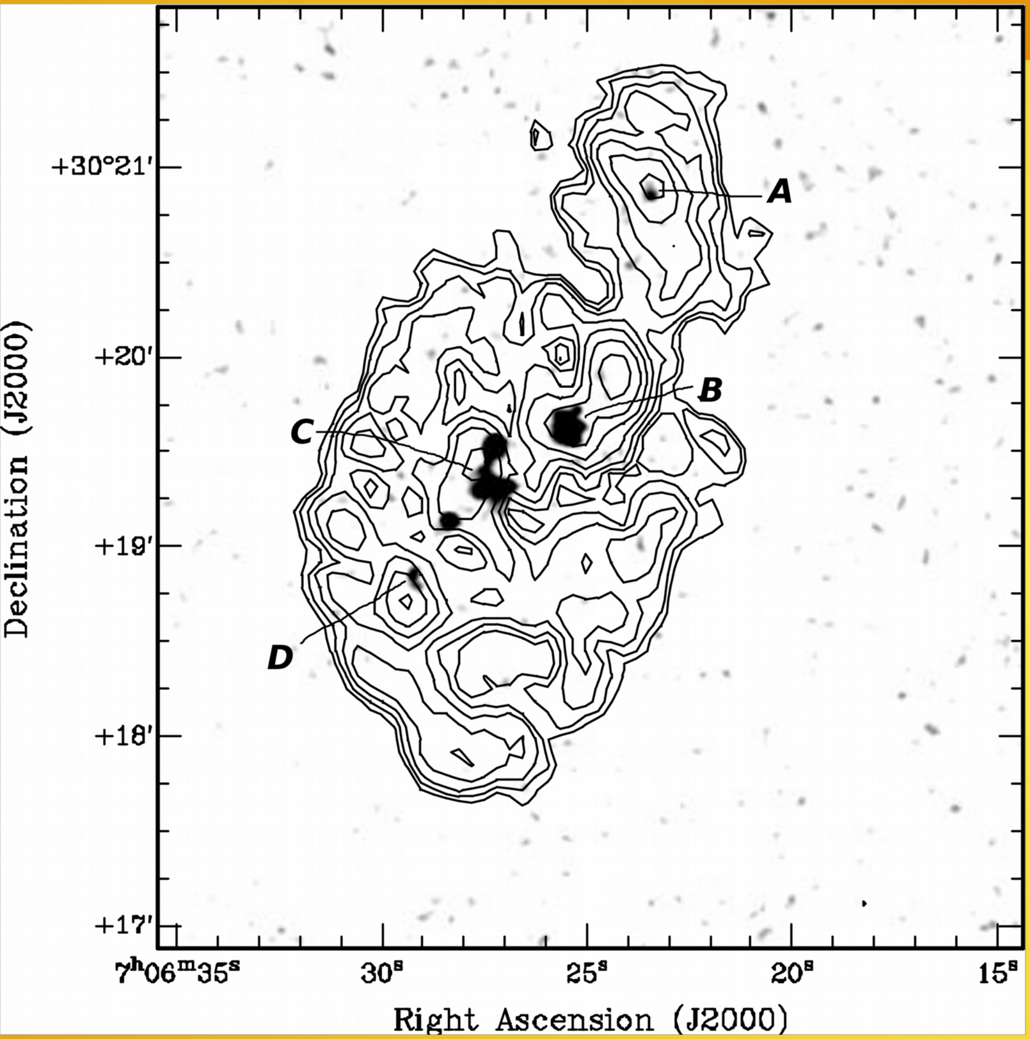
GMRT HI maps overlaid on optical images.
All data are from
Ekta et al. 2008, MNRAS, 391, 881, and
Ekta et al. 2009, MNRAS, 397, 963

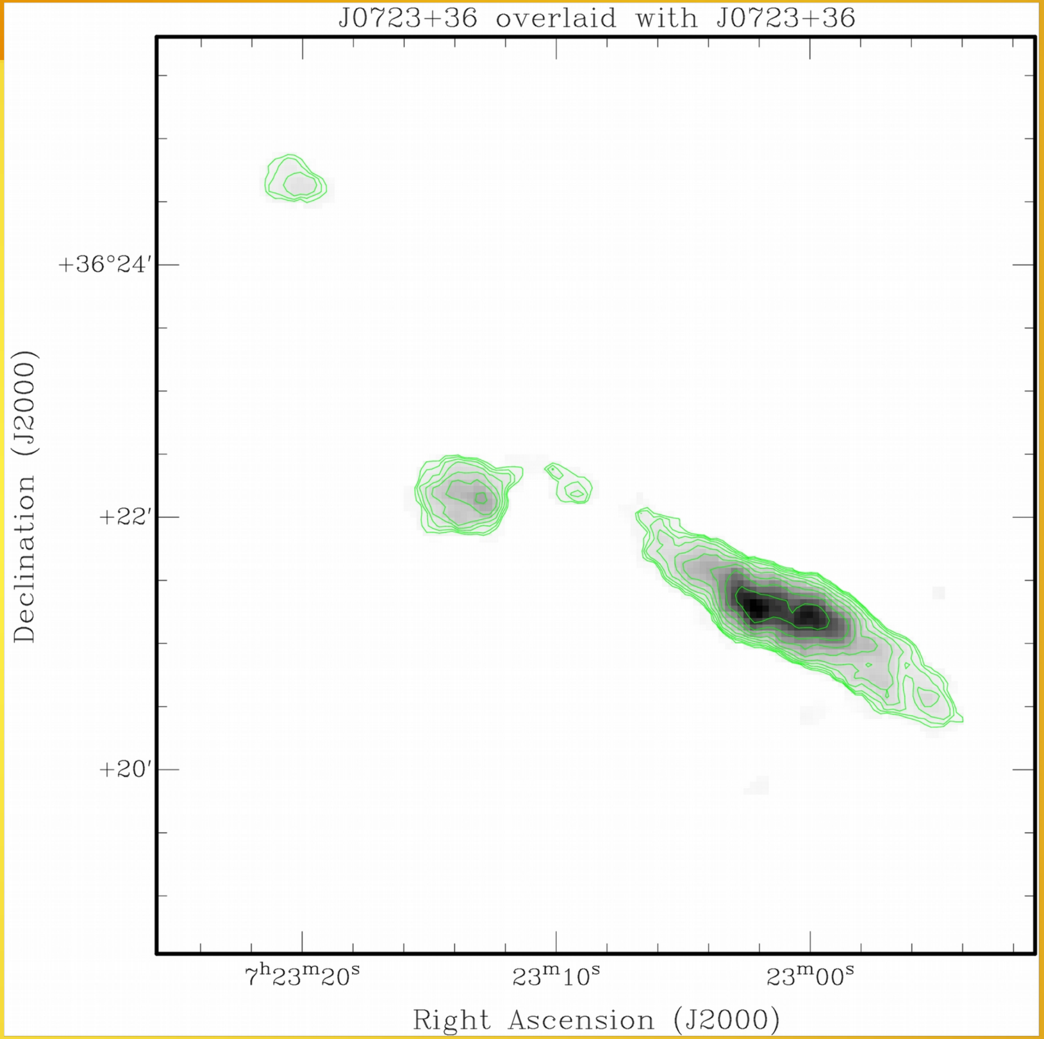


DDO68

SBS0335-052 E,W

GMRT HI maps of very gas-rich merging triplets near the Lynx-Cancer void center: UGC3672 and J0723+36



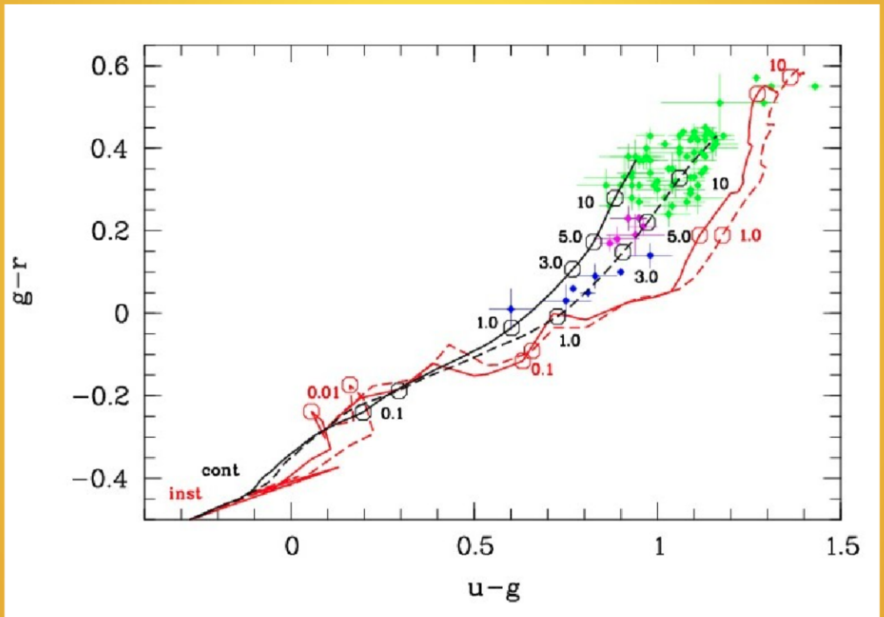


From Chengalur et al., 2017, MNRAS. XMP dwarf UGC3672A with O/H=7.05, MHI/LB=17 and M*/M(bary) < 0.01.

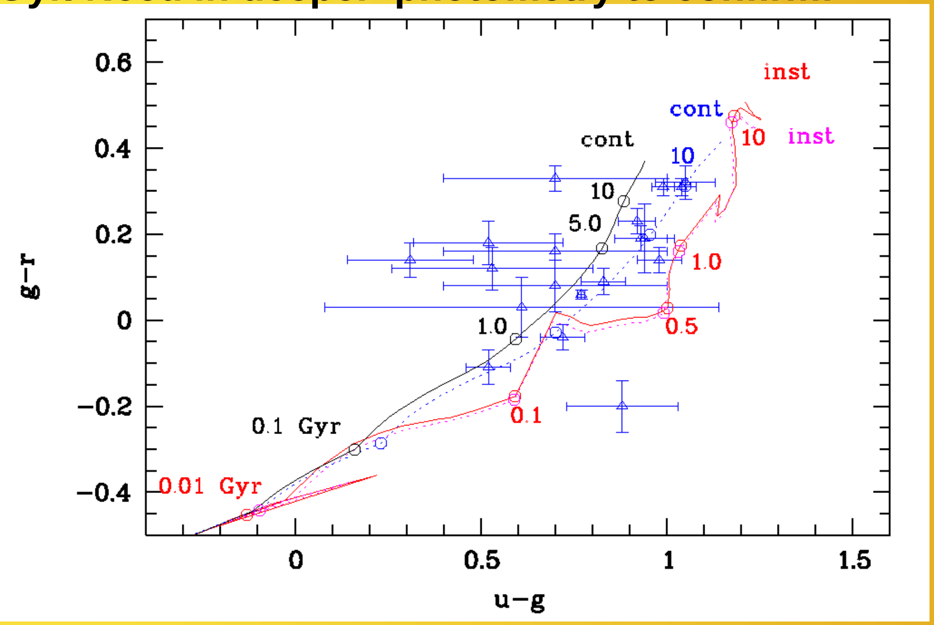
From Chengalur, Pustilnik, 2013, MNRAS. Two very faint optically components have MHI/LB~11 and 28, and M*/M(bary) < 0.01.

Blue ugri colours of outer parts of void gas-rich XMP dwarfs. Indication on non-comological ages of main stellar population (in preparation)

Age indicators: ugr colours of outer parts in 85 Lynx-Cancer void galaxies (on SDSS images) superimposed on PEGASE evolutionary tracks. Most are old. But ~15% show retarded main Star Formation, started only 1-6 Gyr ago (Perepelitsyna etal. 2014)



Preliminary positions of new faint Nearby Void XMP dwarfs on ugr diagram with PEGASE tracks. Errors in u-g are too large, but in g-r positions of most extreme dwarfs are consistent with ages of 1 to few Gyr. Need in deeper photometry to confirm!



Very wide range of XMP dwarf parameters

To model phenomen of XMP galaxies it is worth to summarize the known range of their main properties.

Baryonic masses (mostly of neutral gas): 10^6 — 10^9 Mo

Blue luminosity, or MB= ~-9 to ~-17 mag (Leo P to SBS0335-052E)

The **ratio M*/M(bary)** from <0.01 to ~0.2 (Leo P)

M* ~3*10^5 — 6*10^7 Mo

Dynamical masses, when known on HI vel.field, are of ~5-10 of M(bary).

Morphology: from very LSB dI to Blue Compact Dwarfs

Local environment: from well isolated through dwarf pair or dwarf triplet members to mergers in the 1st passage to almost completed ones

HI morphology: most of mapped XMP objects have disturbed outer and/or internal forms, sometimes with misaligned optical and gas body and/or spins.

Apparent XMP categories and related hypotheses

A. **Pre-merger BCG pairs in voids or near:** **IZw18+C; SBS 0335-052 E,W. Main stellar population seems to have ages < 1-2 Gyr. Candidates to bursting VYG**

B. **Non-void very small dwarf Leo P. Strong secular? metal loss, sits at Ref.Relation O/H vs MB. Probably one XMP dwarf of a few of this type. Can be found in deeper surveys.**

C. **6 isolated void blue very gas-rich LSBDs. Disturbed HI due to Cold accretion? Quiet VYG proxies? Need in deep accurate photometry to limit mass of old population**

D. **4 isolated very gas-rich void BCGs. Disturbed HI morphology. Analog of gas-rich LSBD, but with elevated SF?**

E. **5 small very gas-rich and blue XMP companions in pairs or triplets in voids (apart Little Cub). With low or very low SFR.**

F. **Void advanced (completed) minor mergers (DDO68, UGC772).**

XMP galaxies' diversity. Speculations on its nature.

1. Skillman+2013 and Sanchez Almeida+2017 noticed, discussing low-Z SF galaxies found via SDSS spectra:

due to the known Z-L relation, there should exist a realm of low-Z (Z < Zo/10) dwarfs with MB > -12.5. They can have low SFR, be quiet (Q), LSB disc and hardly detected via emission line spectra. For Z < Zo/30 such QXMP dwarfs should be numerous for M_B > -9.

For modern optical surveys, this limit probes very nearby volume. **Leo P** is one of a few such type **'normal, old'** XMPs, which one could find. **The great majority of other XMPs are outliers from Z-L relation**, **with def.[log(O/H)]~0.4-1 dex**. This **Z deficiency** can be **either immanent of a galaxy** 'secular' evolution or a **transient episode due to** the accident **accretion of XMP piece of gas** from 'outside' (e.g., ambient IGM).

2. **Void environment** is conducive for galaxy slow secular evolution. This is reflected in the **reduced Z** for the same MB, in average by a **factor of 1.5** (our works). **Much larger deviations need either XMP gas "accretion", or a late onset of the main SF episode**. This latter case is similar to the adopted defnition of VYGs.

3. At least one type of void XMP dwarfs, **isolated very gas-rich blue LSB** appear good candidates for VYG. To check this, we need very deep high accuracy photometry in wide range to put the stringer constraints to the mass fraction of old stars.

4. Other types of gas-rich blue void XMPs (BCGs, mergers) may belong to VYGs in phases of elevated SF due to various tidal-induced instabilities. Similar accurate photometry can help.

Conclusions

- ***We present an on-going project of search for and study void XMP dwarfs. We collect all known to-date ~2 dozen XMP galaxies (Z=Zo/50-Zo/30) and examine diversity of their properties. Most of them reside in voids!***

- ***We divide them in the next categories:***

A. 2 BCGs in **interacting/pre-merger pairs** with dI/LSB (**IZw18+C** – in void, **SBS0335-052 E,W** – non-void?)

B. The **least massive** dwarfs with loss of most metals during the secular cosmological evolution (**Leo P**), **non-void.**

C. 6 isolated void LSBD, very gas-rich, with blue 'old' population of non-cosmological ages, with disturbed HI gas

D. 4 isolated BCGs very gas-rich, partly with blue 'old' population

E. 5 small companions in pairs or triplets, very gas-rich and blue (one, **Little Cub**, not in void)

F. 2 void advanced minor mergers (**DDO68, UGC772**), probable analog of A, but dynamically older by ~0.5-1 Gyr.

Nearest prospects

A) Observations:

1. New XMP dwarfs can be found via a more advanced selection among small galaxies in voids.
2. New candidate XMP objects as gas-rich dwarfs in voids may appear as a result of the next generation of the deeper HI blind surveys (Apertif, ASCAP)
3. Multi-wavelength and deep imaging of known XMPs can help to fix the mass-fraction of old stars and address the issue of near Very Young Galaxies.

B) Models and simulations:

High mass resolution simulations of **formation and evolution of dwarfs in voids** would be very helpful. This will improve our understanding and data interpretation. This also will allow to formulate the crucial observational tests, including examination of a real number

of Very Young Galaxies in a nearby Universe.

Thank you for attention!

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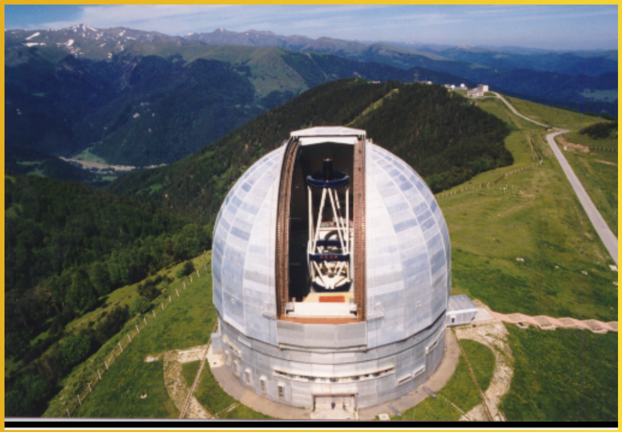


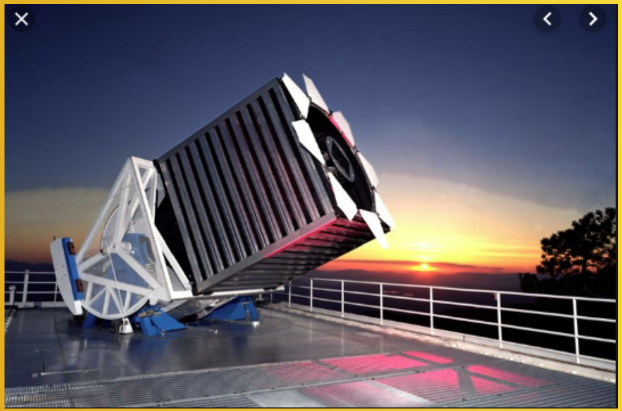

Based on observations at BTA (SCORPIO), SALT (RSS), GMRT with use of key data of great sky surveys SDSS and ALFALFA.