Draft version December 5, 2023
Typeset using LaTeX **twocolumn** style in AASTeX631

Multiple Absorption Sightlines Through a Dark Matter Halo

J. M. Wrobel[1] and F. Walter[2]

[1] *National Radio Astronomy Observatory, P.O. Box O, Socorro, NM 87801, USA*
[2] *Max Planck Institute for Astronomy, Königstuhl 17, D-69117 Heidelberg, Germany*

(Received as ngVLA Memo # 120)

ABSTRACT

We consider how the ngVLA could be used to examine multiple H I absorption sightlines through the dark matter halo of NGC 3115, a nearby lenticular galaxy with an estimated virial radius of about 300 kpc (100′). This cold-gas inventory could fill a gap in the census of baryons in the halo's circumgalactic medium and constrain the origin and fate of the halo's cold baryons.

Keywords: Circumgalactic medium (1879) - Galaxy dark matter halos (1880)

1. MOTIVATION

Dark matter halos resembling the Milky Way's have masses of about 10^{12} solar masses and virial radii of about 300 kpc (e.g., Carlsten et al. 2022). It is rare for such virial volumes to be probed via H I in emission and, even then, such emission studies are limited by sensitivity to radii of only about 50 kpc (e.g., Young et al. 2018).

Generally, the H I traits of virial volumes are studied statistically, by assembling a sample of galaxy halos and examining, per halo, only one H I absorption sightline (e.g., Borthakur 2016). Such a statistical approach can be informative, but a superior approach would be to examine multiple H I absorption sightlines through an individual dark matter halo. To elevate H I absorption studies from a population approach to a superior, individual approach, we leverage on the sensitivity, field of view, spatial resolution, velocity resolution, and spectral dynamic range of the ngVLA (Selina et al. 2022).

2. SUPERIOR APPROACH

This superior approach is illustrated, by example, in Figure 1. It shows a WISE 3.4 μm image of the lenticular galaxy NGC 3115 (Wright et al. 2010). For the Peacock et al. (2015) distance of 10.2±0.2 Mpc, the scale is $1.0' = 2.97$ kpc. The estimated virial radius of the galaxy's halo is about 300 kpc (100′; Carlsten et al. 2022; Karachentsev et al. 2022). Figure 1 shows a reference radius of 50.0 kpc (16.8′). Globular clusters and planetary nebulae trace the galaxy's kinematics out to a radius of 10 kpc and suggest the halo is rotating at about 150 km s^{-1} (Dolfi et al. 2020).

Figure 1 also shows the full width at quarter maximum (FWQM) of the ngVLA primary beam at 1.4 GHz (21 cm) and marks the locations of sources from the FIRST catalog at 1.4 GHz with continuum peaks of S_C = 5 mJy beam^{-1} or more (Helfand et al. 2015). These FIRST sources offer 18 simultaneously accessible sightlines for H I (and OH) absorption studies of the dark matter halo of NGC 3115.

The ngVLA sensitivity calculator[1] for Configuration Revision D reports that if a 100-hour H I observation with the Core+Spiral is tapered to a spatial resolution of 3″ (148 pc), the rms thermal noise for the line would be 30 μJy beam^{-1} at the pointing center in a 1 km s^{-1} channel. Improving over FIRST's spatial resolution of 5″ helps to isolate compact continuum features.

After applying primary beam corrections, the 18 FIRST sources would offer the 3σ line sensitivities $3 \times \Delta S_L$ and corresponding opacity limits $\tau_{3\sigma}$ in Table 1. The opacity performance of less than 5.5% for 18 sightlines through NGC 3115 resembles the less than 6% achieved in a recent single-sightline study with 1 km s^{-1} binning (Borthakur 2016). For NGC 3115 the strongest FIRST source would be sensitive to about $\tau_{3\sigma} = 0.12\%$

Corresponding author: J. M. Wrobel
jwrobel@nrao.edu

[1] https://gitlab.nrao.edu/vrosero/ngvla-sensitivity-calculator

and not run afoul of the ngVLA's absorptive spectral dynamic range (continuum/rms) of 10^{-4}.

Our focus has been on examining the H I (and OH) absorption sightlines toward multiple sources in one ngVLA pointing toward NGC 3115. Byproduct investigations would also be possible, such as studying the 1.4 GHz continuum emission from the galaxy's candidate globular clusters (e.g., Cantiello et al. 2018), candidate satellite galaxies (e.g., Carlsten et al. 2022; Karachentsev et al. 2022), and low-luminosity active galactic nucleus (e.g., Jones et al. 2019).

A similar SKA use case should be developed, potentially paving the way for all-sky studies of individual dark matter halos with the ngVLA and SKA.

The NRAO is a facility of the National Science Foundation (NSF), operated under cooperative agreement by Associated Universities, Inc. (AUI). The ngVLA is a design and development project of the NSF operated under cooperative agreement by AUI.

Facilities: WISE, ngVLA, SKA

Software: CASA (The CASA Team et al. 2022), matplotlib (Hunter 2007)

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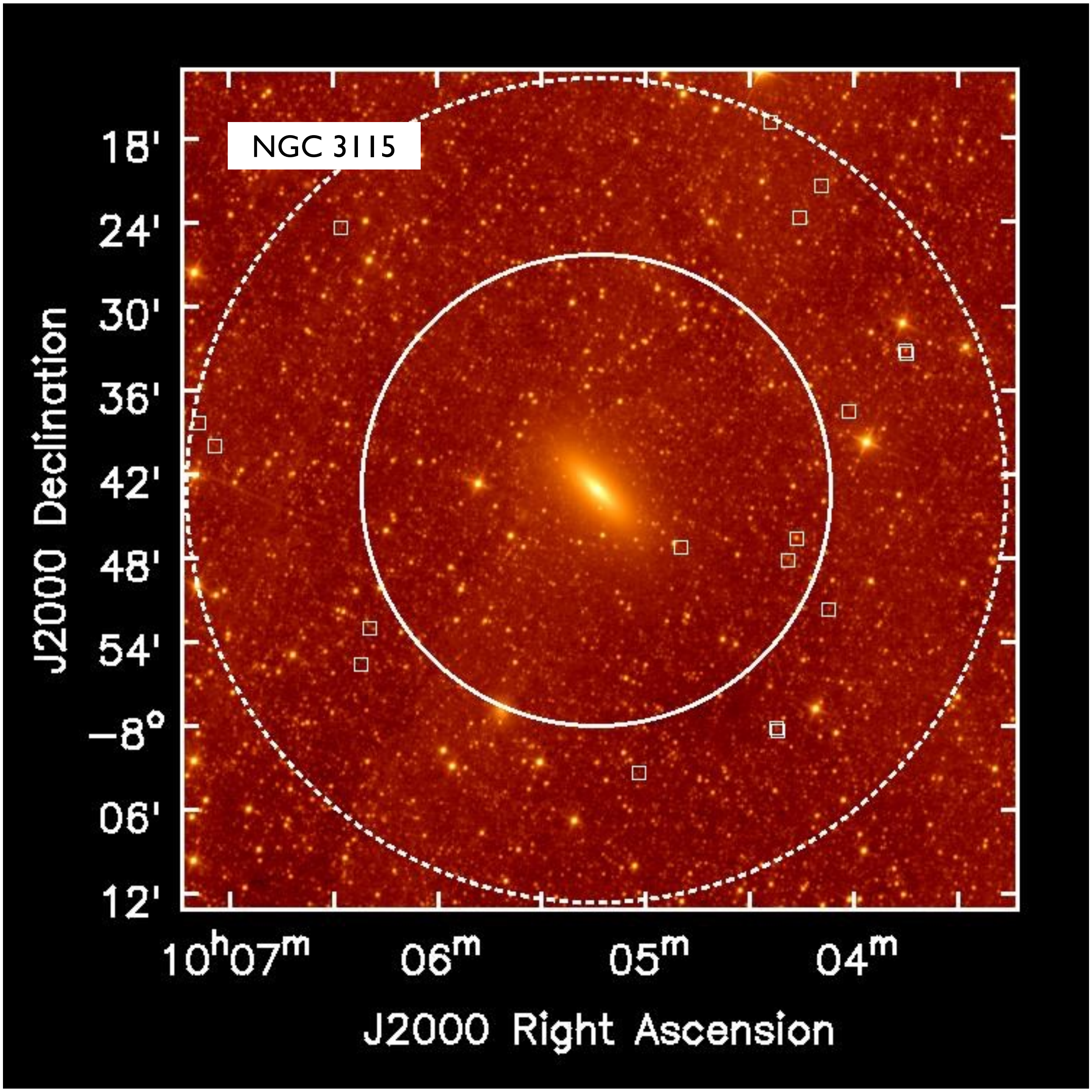

Figure 1. WISE 3.4 μm image of the lenticular galaxy NGC 3115. Each axis spans $\pm 30.0'$ (89.1 kpc). The dashed circle conveys the FWQM of the ngVLA primary beam at 1.4 GHz. Squares mark the locations of FIRST sources. The solid circle shows a reference radius of 50.0 kpc ($16.8'$).

Table 1. Properties of 18 Sightlines Through NGC 3115

Offset ($'$) (1)	Offset (kpc) (2)	α_{2000} (h:m:s) (3)	δ_{2000} ($^\circ$ $'$ $''$) (4)	Peak S_C (mJy beam^{-1}) (5)	$3 \times \Delta S_L$ (μJy beam^{-1}) (6)	$\tau_{3\sigma}$ (%) (7)
7.19	21.34	10 4 49.831	-7 47 6.49	22.46 ± 1.13	98	0.44
14.48	42.96	10 4 19.020	-7 48 2.93	5.73 ± 0.32	126	2.19
14.64	43.43	10 4 16.567	-7 46 34.74	108.01 ± 5.40	127	0.12
18.61	55.22	10 4 7.080	-7 51 35.35	12.58 ± 0.65	156	1.24
18.88	56.03	10 4 1.293	-7 37 25.68	15.80 ± 0.80	159	1.01
18.98	56.31	10 6 19.514	-7 52 57.04	7.07 ± 0.38	160	2.26
20.39	60.50	10 5 1.778	-8 3 16.89	31.55 ± 1.58	175	0.55
20.90	62.01	10 6 21.885	-7 55 31.29	7.81 ± 0.42	181	2.31
21.27	63.09	10 4 22.410	-8 0 7.02	10.67 ± 0.55	185	1.74
21.45	63.65	10 4 21.826	-8 0 14.61	9.90 ± 0.51	188	1.89
24.18	71.75	10 3 45.064	-7 33 8.88	24.10 ± 1.21	229	0.95
24.18	71.75	10 3 44.858	-7 33 15.70	18.96 ± 0.96	229	1.21
24.34	72.22	10 4 15.407	-7 23 34.58	8.79 ± 0.47	232	2.64
26.28	77.96	10 6 27.812	-7 24 15.41	5.03 ± 0.29	271	5.39
27.04	80.22	10 4 9.286	-7 21 20.67	8.59 ± 0.46	289	3.36
27.47	81.50	10 7 4.056	-7 39 50.51	5.49 ± 0.31	300	5.46
28.87	85.64	10 7 8.836	-7 38 16.40	37.29 ± 1.87	340	0.91
29.12	86.40	10 4 23.990	-7 16 45.81	6.71 ± 0.36	348	5.19

Note—Columns (1)-(2): Projected offset from the nucleus of NGC 3115. Column (3): Right ascension. Column (4): Declination. Column (5): Peak continuum flux density and its error. Columns (6)-(7): Three times the primary-beam-corrected rms thermal noise in a 1 km s^{-1} channel and the corresponding opacity limit.