ARTICLE IN PRESS

NRIAG Journal of Astronomy and Geophysics (2016) xxx, xxx–xxx

National Research Institute of Astronomy and Geophysics

NRIAG Journal of Astronomy and Geophysics

www.elsevier.com/locate/nrjag

Statistical study of warps in a sample of spiral and lenticular galaxies

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Received 14 February 2016; revised 29 May 2016; accepted 15 June 2016

KEYWORDS

Galaxies;
Warps in galaxies

Abstract A sample of edge-on (or nearly edge-on) spiral and lenticular galaxies is selected to study the warp phenomenon in their disks. This sample contains 36 disk galaxies selected from Watanabe's catalogue (Watanabe, 1983). We investigate the existence of physical relations between photometric and spectroscopic parameters and the warp degree of galaxies.

1. Introduction

Since the first observations of warp in our Galaxy and in other galaxies (Burke, 1957; Kerr, 1957 and Sancisi, 1976), the origin and persistence of galactic warps have been a matter of research for decades. The disks in most disk galaxies are not flat and their outer parts often show warping of the material away from the galactic plane (Sanchez-Saavedra et al., 1990; Reshetnikov and Combes, 1998; Ann and Park, 2006). Warps are mostly seen in the 21 cm neutral hydrogen line (Sancisi, 1976; Bosma, 1978; Briggs, 1990; Bottema, 1995; Garcia-Ruiz et al., 2002) and in the optical bands (Sanchez-Saavedra et al., 1990; Reshetnikov and Combes, 1999; Drimmel et al., 2000; Reshetnikov et al., 2002). Garcia-Ruiz et al. (2002) analyzed HI observations and found that all edge-on galaxies that have an extended HI disk (with respect to the optical component) are warped. Thus the warps are a common phenomenon and hence must be either continuously being excited or they are stable over long periods of time.

Most of the studies of the warps were a statistical, N-body simulations and theoretical models to explain warp formation (Revaz and Pfenniger, 2001, 2004; Sánchez-Salcedo, 2006; Lodato and Pringle, 2007; Saha et al., 2009; Lodato and Price, 2010; Roškar et al., 2010; Facchini et al., 2013; Sadoun et al., 2014; Haan and Braun, 2014; de Blok et al., 2014; Kim et al., 2014; Kaufman et al., 2015).

Several mechanisms that trigger and maintain warps have been proposed, including tidal interactions between galaxies, inter-galactic magnetic fields, cosmic infall, disk-halo interaction and matter accretion (Battaner et al., 1990; Binney, 1992; Battaner and Jimenez-Vicente, 1998; Jiang and Binney, 1999; Debattista and Sellwood, 1999; Revaz and Pfenniger, 2001; Semelin and Combes, 2005; Shen and Sellwood, 2006; Weinberg and Blitz, 2006; Dubinski and Chakrabarty, 2009).

One of the proposed qualitative studies of the warp phenomena and its relation with physical properties of galaxies is the warp angle introduced by Sanchez-Saavedra et al.

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Peer review under responsibility of National Research Institute of Astronomy and Geophysics.

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http://dx.doi.org/10.1016/j.nrjag.2016.06.001

Table 1 General data of the galaxies in the present sample. Column 1 lists the galaxy number as recorded in Watanabe's catalogue (Watanabe, 1983). Column 2 is the NGC's ID for each galaxy. Column 3 and 4 list the morphological type and type index as recorded in HYPERLEDA database. Column 5 is the total V magnitude (Watanabe, 1983), while column 6 presents the inclination of the galaxy obtained from the HYPERLEDA database. Column 7 is the major diameter at 24.5 V-magnitude in kpc. Column 8 is the axis ratio (b/a). Column 9 is the mean surface brightness in the V band within the isophote at 26 mag/arcsec^2. Column 10 is the absolute magnitude in V-band. Column 11 is the total apparent corrected B-V color. Column 12 is the central velocity dispersion in km/s. Column 13 is the apparent maximum rotation velocity of the gas in km/s. Columns 14–15 are the area of the isophote and the area of the fitted ellipse in arcsec^2 respectively. Column 16 is the warp degree.

No. (1)	NGC (2)	Type (3)	T (4)	V_T mag (5)	Incl deg (6)	$D_{24.5}$ kpc (7)	Axis ratio (8)	SB mag/arcsec^2 (9)	M_v mag (10)	B-V mag (11)	V_{dis} km/s (12)	V_{rot} km/s (13)	A_i arcsec^2 (14)	A_e arcsec^2 (15)	W % (16)
4	4178	Scd	7	11.66	90.0	7.6	0.27	24.07	−18.46	0.35	25.7	116.0	3135.1	2777.1	11
6	4180	Sab	2	12.29	79.6	9.1	0.38	22.57	−20.48			187.6	13.3	11.5	14
8	4192	SABb	3	10.25	90.0	3.4	0.23	23.68	−17.01	0.66	133.6	214.8	1884.3	1799.6	5
10	4197	Scd	7	12.85	78.2	16.5	0.20	23.92	−19.90			120.5	45.9	40.0	13
15	4216	SABb	3	10.02	90.0	7.9	0.10	23.39	−19.19	0.83	201.8	244.0	2790.1	2567.9	8
38	4294	SBc	6	12.17	70.2	4.3	0.37	23.43	−17.90	0.33		90.2	4941.9	4443.7	10
47	4307	Sb	3	11.89	90.0	12.1	0.21	23.63	−19.73			143.7	72.2	68.2	6
50	4312	Sab	2	11.83	90.0	4.2	0.25	23.85	−17.42	0.66	75.8	94.6	1966.2	1891.2	4
55	4324	S0-a	0	11.55	90.0	13.0	0.43	22.88	−20.82	0.81	96.0	143.6	4654.5	4310.3	7
61	4343	Sb	3	12.19	90.0	7.1	0.37	23.12	−19.31			152.8	4229.1	3847.0	9
71	4371	S0-a	0	10.73	79.1	12.2	0.55	23.19	−20.66	0.89	135.9	158.9	4218.6	4100.8	3
93	4417	S0	−2	11.01	90.0	7.9	0.30	22.73	−20.17	0.82	137.1		2030.6	1885.8	7
94	4419	Sa	1	11.11	84.5	0.5	0.33	22.60	−13.78	0.80	101.8	100.0	1479.5	1440.3	3
95	4420	SBc	5	12.24	63.3	8.1	0.43	22.80	−20.13			83.8	3012.6	2831.1	6
100	4425	S0-a	0	11.92	84.5	12.4	0.31	23.16	−20.70	0.79	77.1		4465.1	4076.2	9
106	4442	S0	−2	10.39	90.0	8.9	0.35	22.54	−20.17	0.87	184.2	95.1	3012.2	2860.6	5
108	4445	Sab	2	12.80	90.0	4.0	0.19	23.54	−17.24	0.68		128.5	16.3	14.5	11
119	4469	S0-a	0	11.19	85.5	8.9	0.29	23.55	−19.35	0.86	106.7	184.9	2395.2	2131.6	11
131	4488	S0-a	0	12.15	90.0	8.1	0.32	24.04	−19.28	0.75	57.8		11.1	9.3	16
146	4516	SBab	2	12.72	61.1	5.5	0.47	23.60	−18.63				24.2	21.4	12
153	4527	SABb	4	10.54	81.2	25.8	0.28	23.30	−21.90	0.72	135.3	166.4	2316.0	2137.5	8
157	4533	Scd	7	13.75	90.0	10.7	0.24	24.09	−18.70			69.6	77.1	67.6	12
161	4550	S0	−2	11.49	90.0	5.5	0.30	22.73	−18.87	0.78	103.2	157.0	1057.4	974.2	8
166	4569	SABa	2	9.64	70.8	1.8	0.39	23.43	−16.00	0.61	140.1	161.1	3375.8	3018.2	11
167	4570	S0	−2	10.62	90.0	16.7	0.31	22.71	−21.86	0.84	188.7		1916.0	1691.1	12
179	4607	SBbc	4	12.85	90.0	17.6	0.19	24.27	−20.08	0.75		98.9	181.1	162.8	10
184	4623	S0-a	0	12.30	90.0	10.8	0.28	23.57	−20.19		77.2		3491.2	3102.1	11
206	4710	S0-a	0	10.80	90.0	16.0	0.24	23.22	−20.82	0.77	118.3	160.0	682.8	614.5	10
210	4746	Sb	3	12.57	90.0	10.0	0.24	23.34	−19.93			152.2	3.9	3.5	10
224	3877	Sc	5	11.12	83.2	12.4	0.20	23.47	−19.95	0.65	86.1	154.0	609.0	561.7	8
236	3922	S0-a	0	12.62	90.0	5.1	0.37	23.39	−18.43		86.2	33.4	2804.3	2454.7	13
253	4085	SABc	5	12.27	80.4	5.0	0.23	23.27	−18.43	0.45		125.0	2934.9	2610.7	11
254	4088	SABc	5	10.60	71.2	10.4	0.36	23.10	−20.12	0.49	54.3	158.4	1750.1	1516.9	13
256	4100	Sbc	4	11.13	79.6	12.9	0.30	23.44	−20.23	0.60	75.5	180.6	2946.1	2655.3	10
257	4157	SABb	3	11.20	90.0	13.4	0.18	23.89	−19.56	0.64	93.9	188.9	66.4	56.9	14
260	4220	S0-a	0	11.27	90.0	8.2	0.30	22.95	−19.80	0.79	110.6	162.7	1731.9	1678.7	3

(1990, 2003). In a study of Reshetnikov and Combes (1999), they did not find a correlation between the warp angle and the blue absolute magnitude for some warped spiral galaxies. Radburn-Smith et al. (2014) studied the gaseous H I warp of NGC 4565 and they found a clear correlation of young stars (< 600 Myr) with the warp, but no coincident old stars (> 1 Gyr), which places an upper limit on the age of the structure.

In this work, we study the possible correlations between the warp degree (W) and different photometric and spectroscopic parameters of the present sample of disk galaxies (such as the major diameter, axis ratio, mean surface brightness, absolute magnitude, B-V color, central velocity dispersion and rotation velocity). In this study we used a cosmological model with $H0 = 70\ km\ s^{-1}\ Mpc^{-1}$, $\Omega m = 0.3$ and $\Omega\Lambda = 0.7$ for all the calculated numerical values. The paper is laid out as follows. In Section 2 the criterion describing the warp degree (W) is outlined. In Section 3, the sample of galaxies is described. The results and discussion are presented in Section 4 while the conclusions are summarized in Section 5.

2. The warp criterion

One of the proposed criteria used to describe the presence of warp in a galaxy is the warp angle Ψ defined as the angle between the major axis and the line from the galactic center to the highest observed departure of the plane of symmetry is the warp angle (Sanchez-Savedra et al. 1990, 2003).

Please cite this article in press as: Hendy, Y.H.M. et al., Statistical study of warps in a sample of spiral and lenticular galaxies. NRIAG Journal of Astronomy and Geophysics (2016), http://dx.doi.org/10.1016/j.nrjag.2016.06.001