NGC 2403: Caldwell 7

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Abstract

The available literature regarding NGC 2403 was analysed to produce a discussion on the Galaxy. NGC 2403 is a SAB(s)cd type galaxy at a right ascension 07h 36m 51.4s, declination $+65^o$ 36' 09" at a distance of $\approx 2.5Mpc$, in the constellation Camelopardalis. The distance to the galaxy was determined using the Cepheids of the galaxy and the properties of the galaxy were discussed including its kinematics, mass distribution and stellar population. The galaxy lies on the Tully-Fischer relation and does not contain an AGN (Active Galactic Nucleus).

Contents

1 General Properties

1.1 Classification

The galaxy NGC 2403 was discovered by the German-British astronomer William Herschel on November 1, 1788.[1] This galaxy can be seen as part of the Camelopardalis constellation.

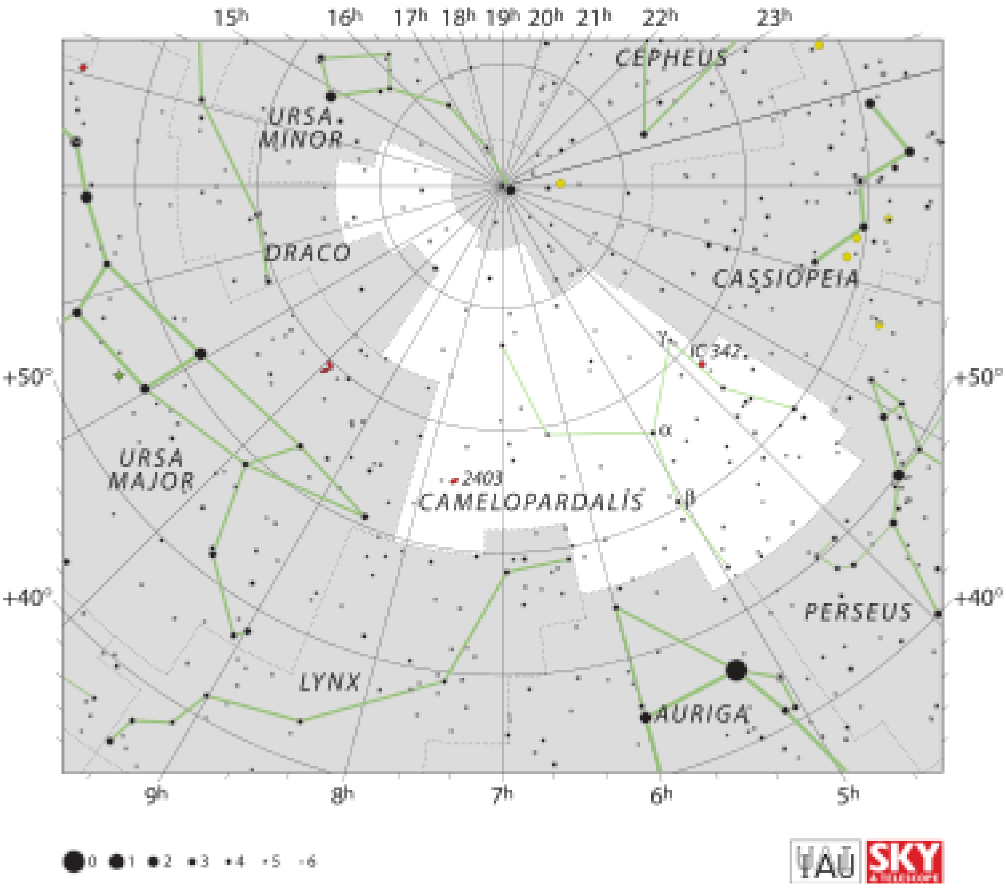


Figure 1: The Constellaton of Camelopardalis with NGC 2403 labelled

Since it's relatively near, and almost face-on from our perspective, NGC 2403 displays intricate details in its spiral arms when viewed with even small telescopes or binoculars.

NGC 2403 is classified as an Intermediate Spiral Galaxy of type SAB(s)cd[2] in the galaxy morphological classification system devised by Gerard de Vaucouleurs.SAB indicates that this is a spiral galaxy which is in between the classification of a barred and an unbarred galaxy. The (s) in this classification scheme indicates that the galaxy does not possess a ring-like structure. The cd indicates that the galaxy is between that of a SAB(s)c and SAB(s)d type, in a 'transition' stage. This is due to its loosely wound spiral arms, clearly resolved into individual stellar clusters and nebulae as well as a small, faint bulge.

1.2 Distance + Determination

Many efforts have been made to determine the distance to NGC 2403, each of them using the Period-Luminosity relation of Cepheid Variables as this would be the most straightforward,

Figure 2: The galaxy NGC 2403

efficient and accurate method for a galaxy with such prominent Cepheids. The earliest available analysis is that of G.A. Tammann A. Sandage, who analysed the Period-Luminosity of a number of Cepheids to obtain a distance modulus of 27.56 Magnitudes[3]. I feel that the most accurate measurement would be that of Christopher W. McAlary and Barry F. Madore in 1983. They obtained infra-red measurements of 5 Cepheid Variables in the galaxy and when they applied the Period-Luminosity relation they found a distance modulus of 28.15+-0.2 magnitudes[4]. This value was reinforced in January 1988, when Barry F. Madore analysed the period-luminosity relation for 8 Cepheids to obtain a value of 27.57+-0.14 magnitudes[5]. These values all roughly lie within each other's margin of error so I would trust their validity.

1.3 Structural Components

NGC 2403 is a spiral galaxy roughly 50,000ly in diameter[6] with loosely wound and diffuse spiral arms coming from a poorly defined nucleus with no apparent bulge. With an ascension: 07h 36m 51.4s[2] we can clearly observe its features, such as its abundant giant star forming HII regions, marked by the telltale reddish glow of atomic hydrogen gas. In the spectrum of this galaxy we can see a large spike for the wavelength of atomic Hydrogen at 656nm in Figure 3.

The northern spiral arm connects it to the star forming region NGC 2404, which is a massive HII region, which was discovered by Gulliaume Bigourdan on February 2, 1886.[7] NGC 2404 is approximately 2,000ly in diameter making it one of the largest known HII regions.We can also observe darker regions called dust lanes where light is blocked by gas and dust within the galaxy. This galaxy contains 30-40 Wolf-Rayet stars which are a rare heterogeneous set of stars with unusual spectra showing prominent broad emission lines of ionised helium and highly ionised nitrogen or carbon. The dark matter distribution of this galaxy has not been discussed

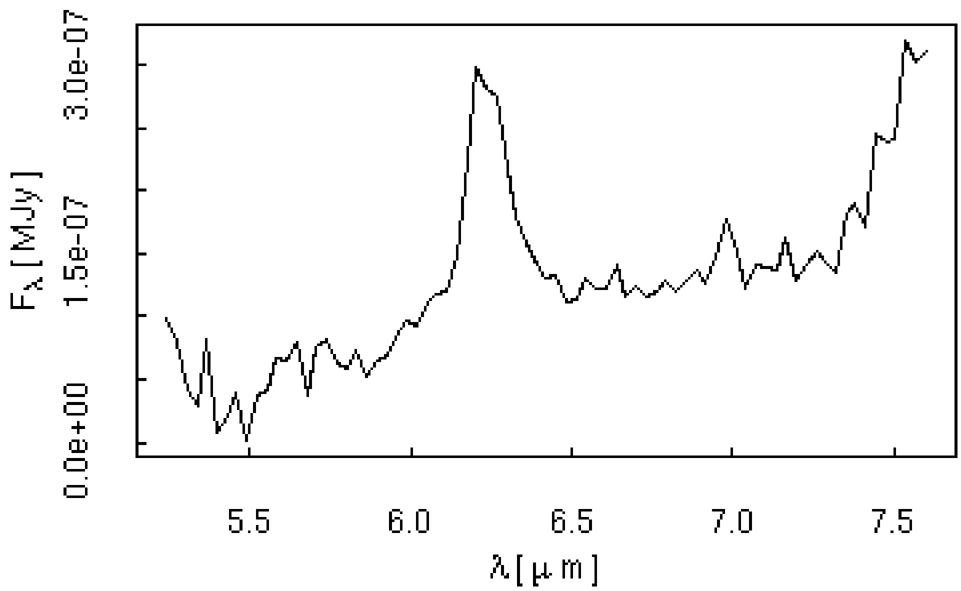


Figure 3: The emission spectrum of NGC 2403

in literature however I would say it's reasonable to assume it is evenly distributed throughout the halo analogous to the Milky Way. It is not entirely clear whether there is a black hole at the centre of the galaxy, however Jun'ichi Kotoku argues that the spectrum and high luminosity of a source within the galaxy suggests that there is a mass-accreting black hole binary with a mass 15 solar masses,[8] which would be incredibly small compared to the Supermassive black hole which is at the centre of our own Milky Way.

1.4 Group Membership

NGC 2403 is part of the M81 group, which derives its name from the famous M81/M82 pair of galaxies discovered in 1784.[9] This group contains the constellations of Ursa Major and Camelopardalis. This is one of the closest groups to our local group at a distance of roughly 12 million light years, according to 1993 measurements of the Hubble Space Telescope under the direction of Wendy Freedman of the Carnegie Institution of Washington by measuring the periods of 32 Cepheid variables in M81 with the pre-repair Wide Field/Planetary Camera (WFPC I), and corrected for Hipparcos results.[10]

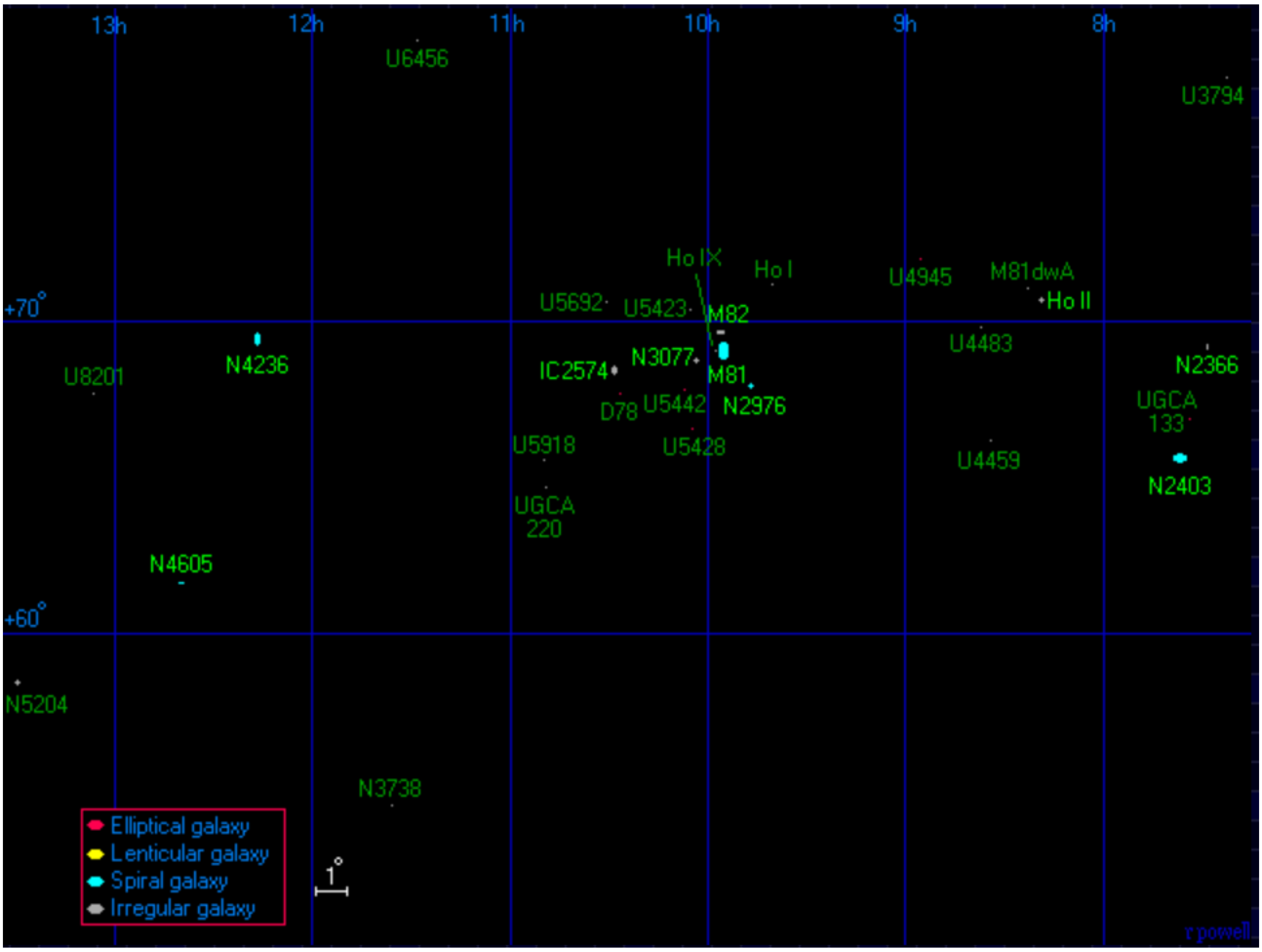
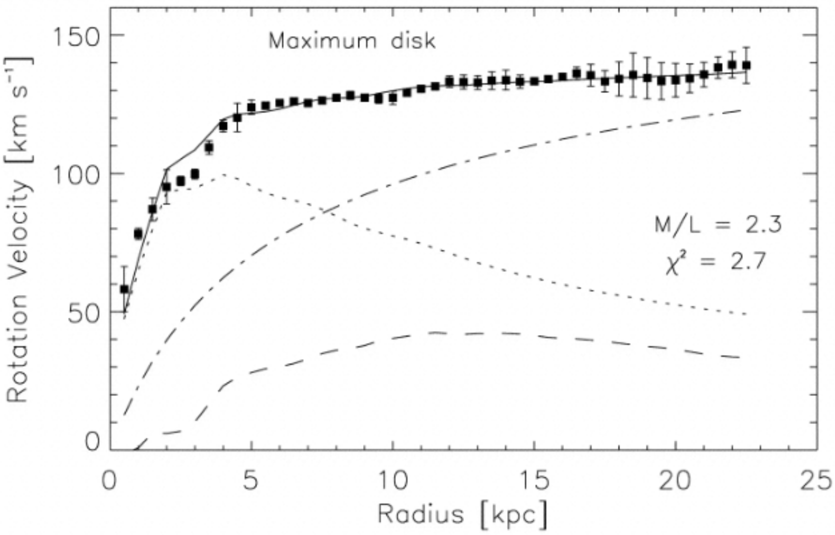


Figure 4: The group M81 which includes NGC 2403

2 Kinematics

The Kinematics the Galaxy NGC 2403 were analysed through studying the properties of the ionised clouds of H I gas by Fraternali et al. in 2002.[12]

Using this analysis, they were able to derive a rotation curve for the galaxy. Note that this is the maximum disk model which gives a scaling factor (M/L) for the stellar component of 2.3. The filled squares show the observed rotation curve, the contributions by gas (dashed), stars (short dashed), and DM halo (long-short dashed) and the total rotation velocity (solid).



Curve.PNG

Figure 5: Rotation Curve of NGC 2403

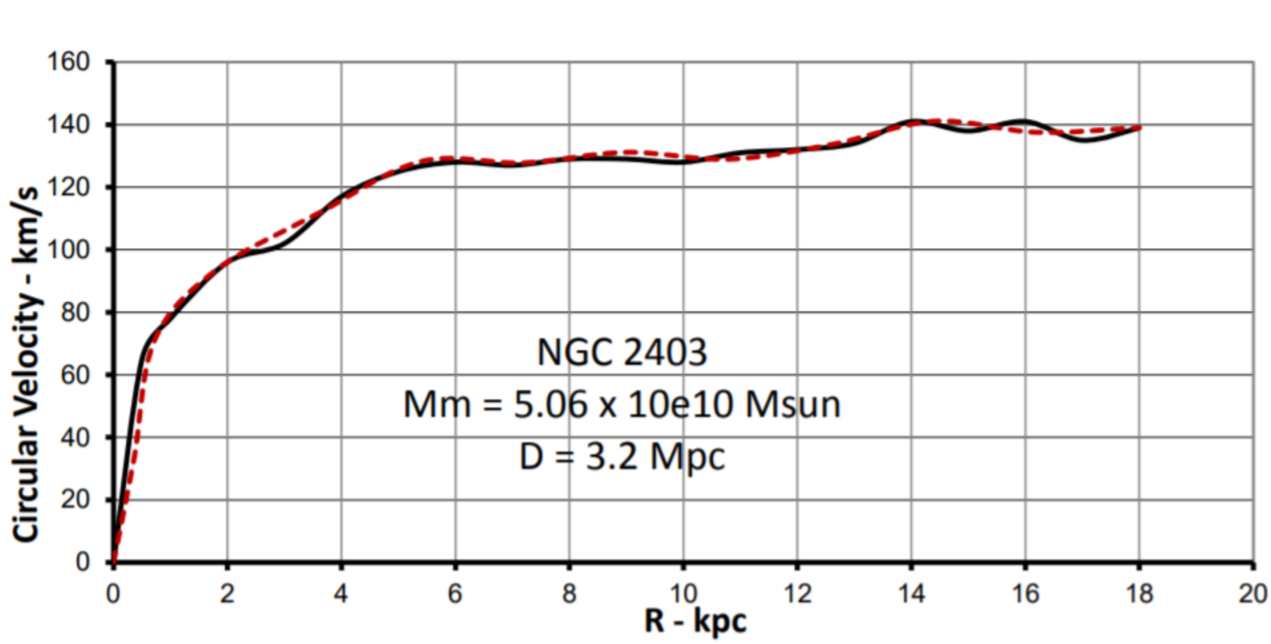
From this, we observe a rather typical asymmetric rotation curve for a spiral galaxy.This includes a steep slope as we move out from the bulge and a flat curve out at the spiral arms. It is worth noting that this experimentally created curve does not correspond with the expected curve from observable matter,A Dark Matter distribution throughout the disk has been proposed as the reason for this discrepancy.

We observe the maximum rotational velocity to be roughly 132km/s and the velocity along the flat part of the curve to be the same. This is significantly smaller than the velocity 240km/s of the Milky Way and so I would predict NGC 2403 to be much smaller than our own galaxy.

The galaxy has been found to have a redshift of 0.000445 which corresponds to a radial velocity of 133km/s.

3 Mass and Mass Distribution

The total mass of the galaxy NGC 2403 was determined to be $5.06 \times 10^{10} M_\odot$ [13] The mass distribution of our galaxy can be determined by analysing its rotation curve, as a given rotation speed at a certain radius can be used to determine the mass enclosed. Geoffrey M. Williams has done this type of analysis. He has analysed the galaxy using the Newtonian Disk Model which assumes that virtually all the mass of stars, gas, dust and dark-matter is contained as a “flattened” mass within the galactic disk, which extends out to the edge of the observable rotation. Bearing this in mind, he has used the data published from THINGS: The HI Nearby Galaxy Survey, to graph a simplified rotation curve for the galaxy which can be used to determine its mass distribution.



rotation.PNG

Figure 6: Rotation curve for NGC 2403 derived from THINGS

Using this newly derived rotation curve and the relation between rotational velocity and mass he was able to graph the mass distribution of the galaxy.

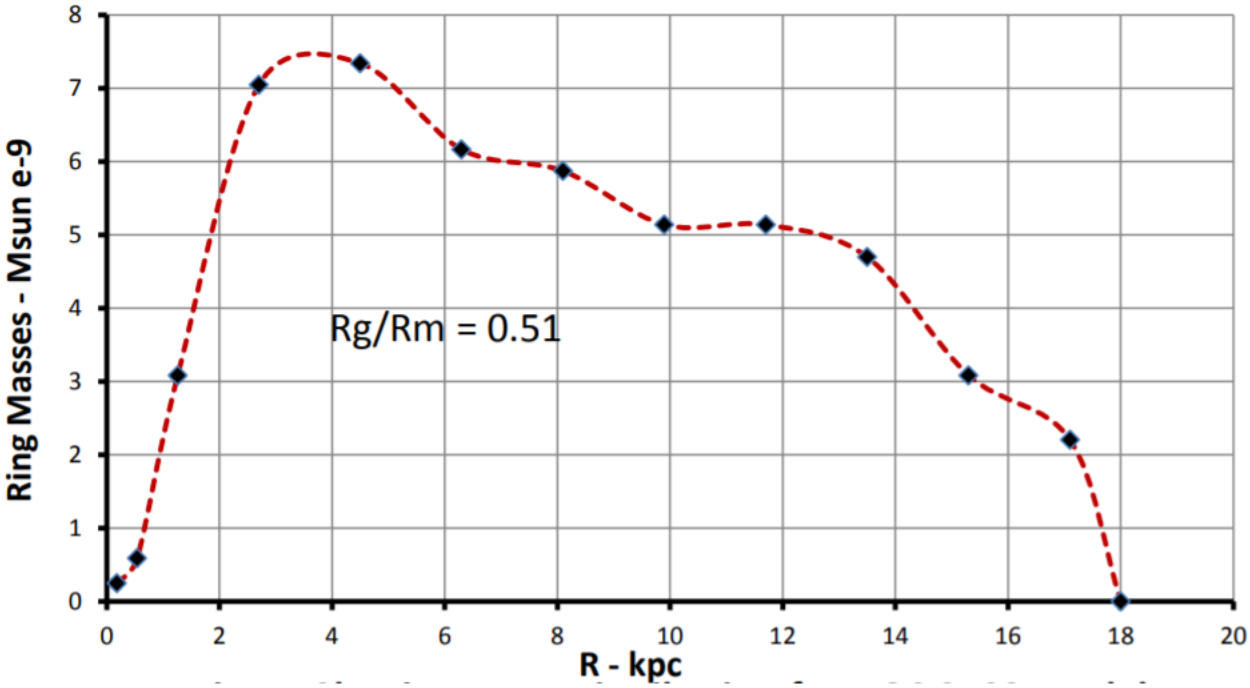
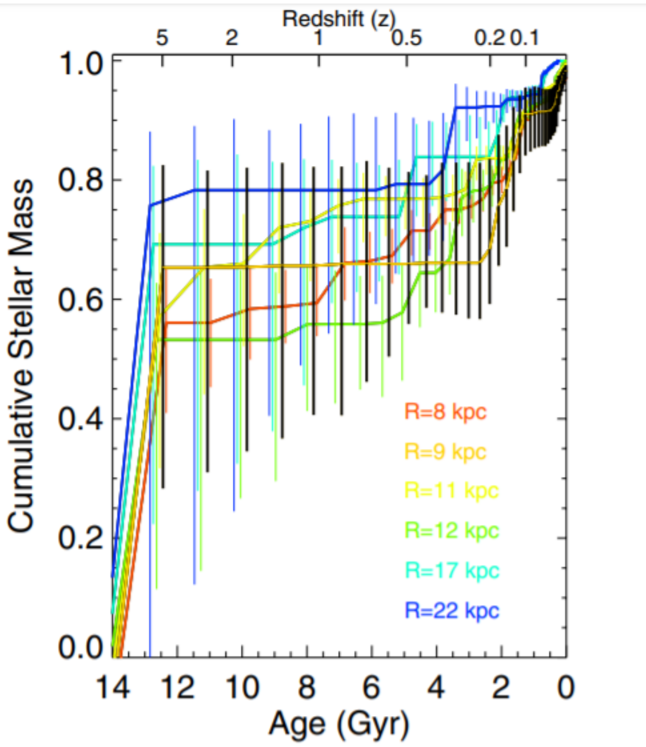


Figure 7: Mass dispersion of NGC 2403

We can see from this that that the mass of the galaxy is well dispersed radially in the disk. It can also be speculated for similar reasons that the dark matter of the galaxy is distributed evenly throughout the disk. I was unable to find any discussion of the mass fractions of the structural components.

4 Stellar Population

There have been numerous studies which have attempted to analyse the stellar population of NGC 2403. Williams et al.(2013) did a very thorough analysis which included many fascinating results. They have a figure which shows the cumulative stellar age distributions of all of the fields sensitive to the old stellar populations.[14]



pop.PNG

Figure 8: Cumulative Stellar mass vs. Age

The different fields are color-coded by distance from the galaxy center. From this,they dervied the surface density profile evolution for the disk outside of three scale lengths, No evolution in the scale length of the surface density profile is seen, as expected given that all of the cumulative distributions are consistent with one another.

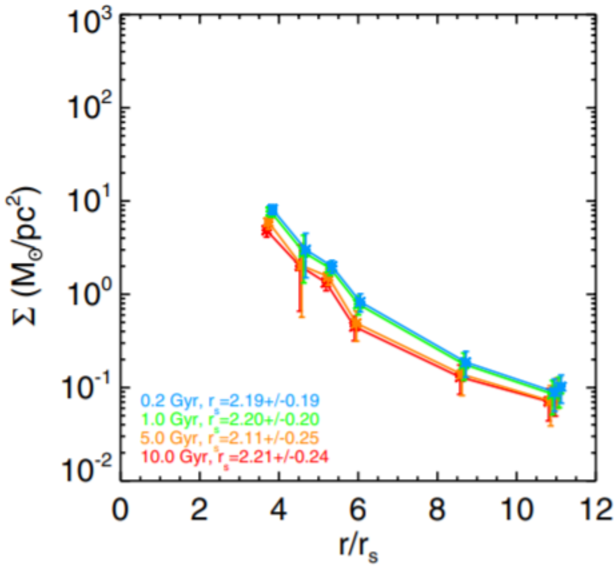


Figure 9: The radial surface density profile of NGC 2403 computed at several epochs

These results suggest little radial variation in the age distribution of the stellar populations in NGC 2403 with galactocentric distance.

In this paper, the Median ages and mean metallicities are also plotted as a function of radius.

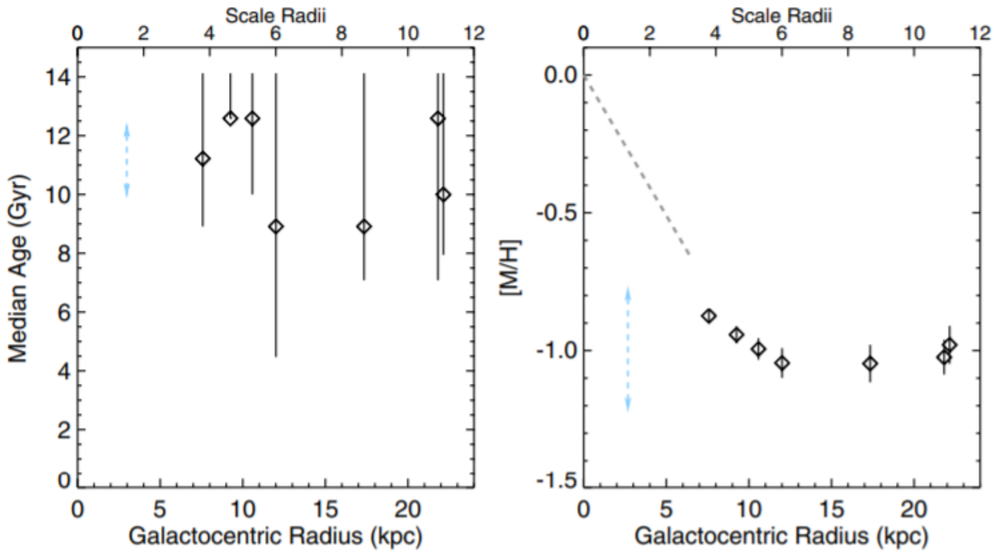


Figure 10: Median Age and Mean Metallicities as a function of Radius

The lack of both an age gradient and an outer disk metallicity gradient is consistent with our earlier conclusions. The metallicity has a mean value [Fe/H] 1 which would be similar to most spiral galaxies and suggest an old star population. However there is evidence for a metallicity gradient inside of 12kPc, in the old stars which make up the majority of the population. But without metallicity measurements inside of three scale lengths we cannot reliably address the possibility of a metallicity gradient in the inner disk,even for the old stars. Overall, the measured median ages are consistent with beingthe same at all radii outside of 7 kpc, although the uncertainties are relatively large. However, the metallicity measurements show a constant mean metallicity in the outer disk of NGC 2403 , spatially coincident with the surface density upturn in the old population. Therefore, the enhanced surface density appears to be due to a population of very well-mixed old stars with relatively low metallicity.

This paper also includes an analysis of the recent SFR (Star Formation Rate) of our galaxy.

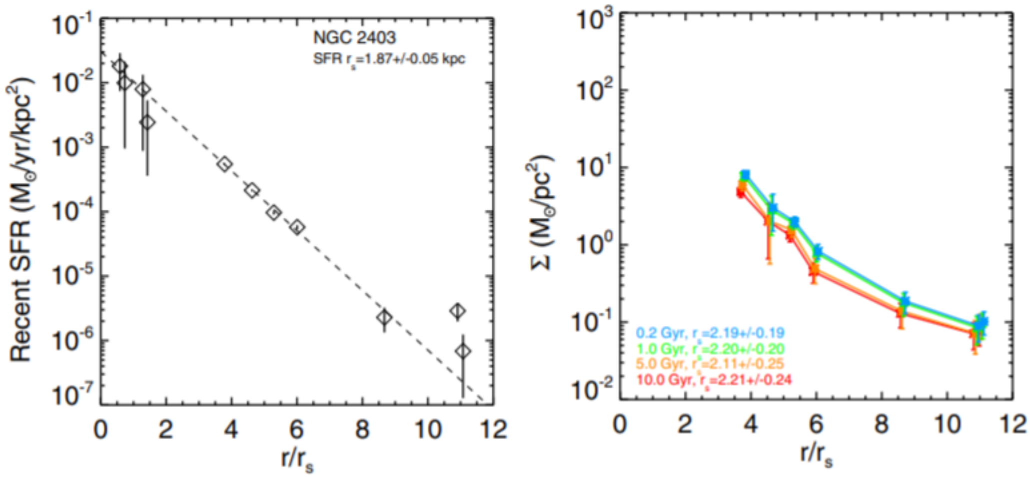


Figure 11: SFR (Star Formation Rate) of NGC 2403

The SFR profiles are shown as a function of disk scale length (as measured from disk surface brightness), out to 11 scale lengths. Therefore differences in the steepness of the profiles show differences in how the star formation falls off relative to the overall disk surface brightness. We can see a typical distribution that has remained consistent over a long period of time.

5 Tully Fischer Relation

NGC 2403 lies on the Tully Fischer relation as we would expect from a Spiral Galaxy of its type. Due to the clear visibility of the Cepheids in this galaxy its distance has been well determined as was previously discussed. The rotation curve for this galaxy is also well known mainly due to the kinematics of the HI clouds. Due to these properties and the galaxies clear visibility it was one of the galaxies used to develop the Tully-Fischer relation. [15] It is also a Tully-Fisher calibration galaxy, and is used as a standard by which other spiral (and occasionally lenticular) galaxies are fit to the Tully Fisher relation for the purposes of determining their distances.

Tully.PNG

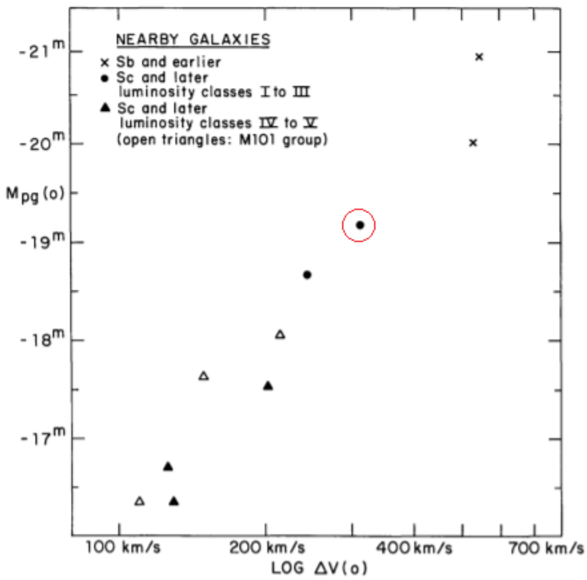


Figure 11: Tully-Fischer relationship with NGC 2403 circled

This plot is taken from the original paper where the Tully Fischer relation was proposed, with NGC 2403 circled in red. We can see NGC 2403 sits directly in the middle of the plot with a clear direct correlation between its magnitude and rotational velocity

	(1) Type	(2) Lc	(3) Δ	(4) m_{pg}	(5) A_B	(6) A_ξ	(7) $M_{pg}(o)$	(8) a	(9) b	(10) A	(11) ξ	(12) ΔV	(13) $\Delta V(o)$
Local Group													
M31	SAb	I–II	0.710 Mpc	$4^{\mathrm{m}}33$	0.44	$0^{\mathrm{m}}60$	$-20^{\mathrm{m}}96$	197	92	41 kpc	78°	535 km/s	546 km/s
M33	SAcd	II–III	0.817	6.19	0.12	0.17	−18.66	83	53	20	55	198	242
M81 Group													
M81	SAab	I–II	3.25	7.85	0.07	0.23	−20.01	35	14.4	33	58	450	530
NGC 2403	SXcd	III	3.25	8.80	0.24	0.17	−19.17	29	15	27	60	265	306
NGC 4236	SBdm	IV	3.25	10.05	0.02	–	−17.53	26	8.7	25	75	195	202
IC 2574	SXm	IV–V	3.25	10.91	0.04	–	−16.69	16	8.0	15	68	117	126
NGC 2366	IBm	IV–V	3.25	11.41	0.19	–	−16.34	10.0	5.3	9.5	63	115	129
M101 Group													
NGC 5585	SXd	IV	7.24	11.25	0	–	−18.05	8.7	5.7	18	51	166	214
NGC 5204	SAm	IV	7.24	11.62	0	–	−17.68	8.0	4.2	17	57	127	151
Ho IV	IBm	IV–V	7.24	12.95	0	–	−16.35	6.5	2.7	14	70	103	110

PNG

Figure 12: Original data readings taken by Tully and Fischer with NGC 2403 circled

6 AGN

I think it is fair to assume that NGC 2403 is not an active galaxy and does not contain an AGN. The optical spectrum of NGC 2403's nucleus does not containing any of the hallmarks of an active galaxy, such as the characteristic narrow and/or broad emission lines in the optical.

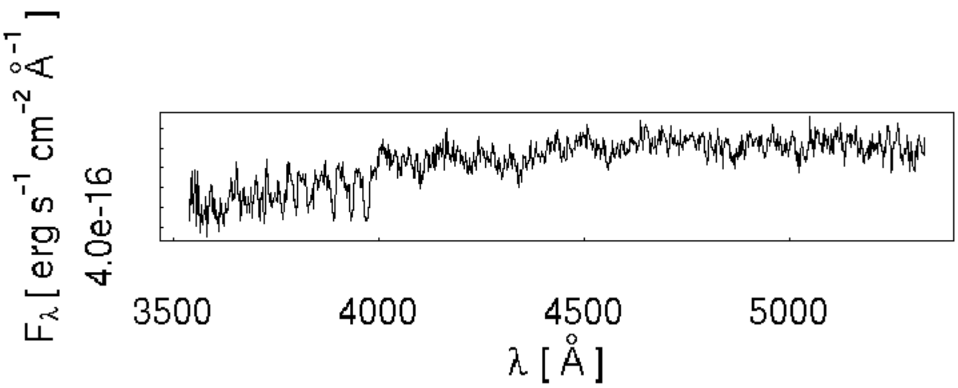


Figure 13: NGC 2403's Optical Spectrum, showing no sign of characteristic AGN features

Aside from this, it is clear from the mass distribution of the galaxy which was discussed earlier that there is no super-massive black hole at the centre of the galaxy.

7 Supernovae

There have been two reported supernovae in the galaxy NGC 2403. The first was SN 1954J, which attained a magnitude of 16 at its brightest. However, very interestingly Schuyler D. Van Dyk et al. (2005) [16] suggests that Through imaging and spectroscopy obtained with the Keck 10 m telescopes, he has confirmed that the precursor star of SN 1954J has survived a superoutburst. It is not a Supernova, in the classical sense, but an "impostor" masquerading as a Supernova. He says that The apparent survivor has changed little in brightness and color over the last 8 years. He revealed this "supernova impostor" as a highly luminous $\left(M_V^0 \approx -8.0\text{mag}\right)$, very massive ($M_{\text{initial}} \geq 25 M_{\odot}$), eruptive star, now surrounded by a dusty nebula.

SN 2004dj occurred within the young, massive stellar cluster Sandage-96 in a spiral arm of NGC 2403 and was the nearest and brightest supernova of the 21st century.[17]

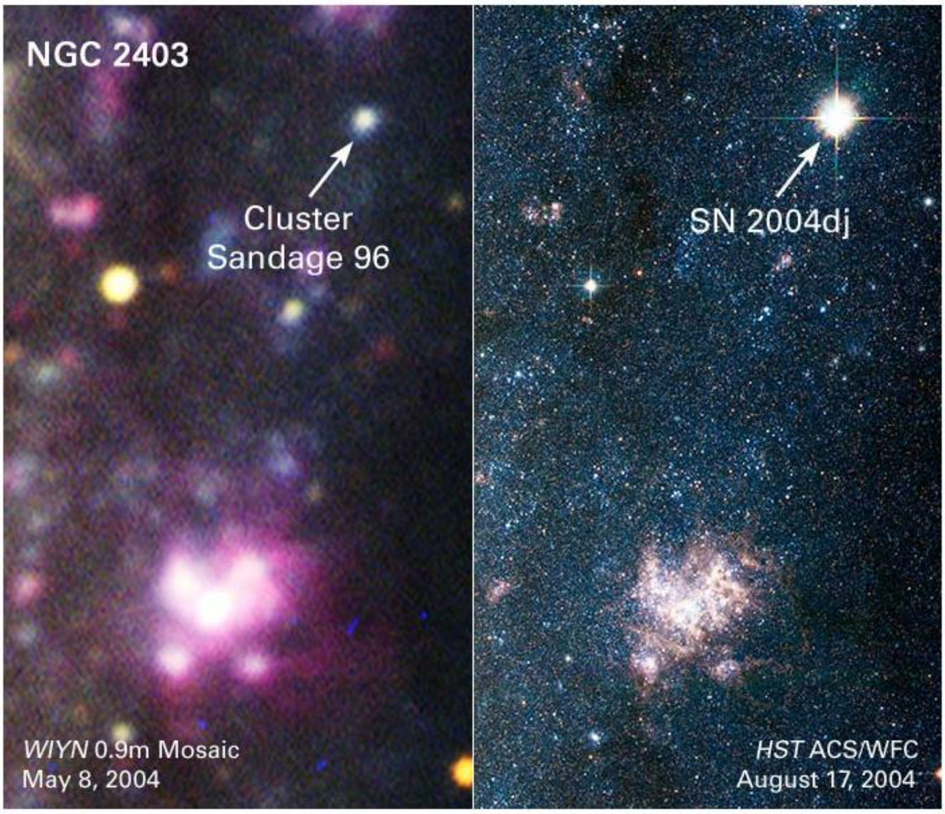


Figure 14: Cluster Sandage 96 before and after SN 2004dj

8 Conclusion

In summary, NGC 2403 appears to be a reaonably typical spiral galaxy which bears striking similarities to M33 (Triangulum Galaxy) which lies within the local group. The favourable location and inclination of the galaxy allow it to be observed very easily which has led to a great degree of study of the galaxy. It's distance was well determined by numerous studies as was its mass and mass distribution. Much of the research in to this galaxy is based on its supernovae both of which were of great interest to the astrophysics community.

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