Nigerian Journal of Physics (NJP)
ISSN online: 3027-0936
ISSN print: 1595-0611
DOI: https://doi.org/10.62292/njp.v34i4.2025.421
Volume 34(4), December 2025

Correlation of Spin Parameters with the Masses and Ages of some Barred Spiral Galaxies

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ABSTRACT

Cosmology is the study of the universe, or cosmos, regarded as a whole. Stars are collected into galaxies, galaxies are gravitationally bound into clusters, and even clusters of galaxies are found within larger superclusters. Galaxies are classified depending on their morphology: elliptic, lenticular, spiral or irregular. It is particularly interesting to study the structure of spiral galaxies, which is usually well differentiated in a central bulge, with a high concentration of stars, and a flat disk made up with younger stars, dust and gas. The arm of this work is to determine correlation between spin parameters, the total masses, gas masses and ages of some barred galaxies. The spin parameter happen to be the cardinal tangible parameter in verifying the morphological and visual feature of a spiral galaxy. Starting from the theoretical spin parameter equation suggested by Peebles, we analyzed the spin parameters of some barred galaxies using $\lambda = \frac{2^{1/2} V_D^2 R_D}{G M_H}$. In determining the correlation we use the Bravais Pearson correlation and made predictions using polynomial in MATlab.The spin parameter for Milky Way galaxy is 0.0253 which is in agreement with what is recorded in many literatures, Andromeda is 0.0491. The predicted ages for NGC 4258 was 12.63 billion years. In this work spin parameters of ten barred galaxies were calculated and their correlations gotten.

Keywords:
Galaxies,
Barred Spiral galaxies,
Spin parameter.

INTRODUCTION

The assessment of notions on the shape and source of the Universe demonstrates that humanity has perpetually place itself in the middle of invention. As astronomical facts have pile up, these anthropocentric held belief had to be forsaken one after the other. Initially it was a natural notion that the solid Earth is at rest and the celestial objects all rotate around us, we have come to the awareness that we reside in a conventional sized planet orbiting a standard-sized sun, which the Solar System is at outside boundary of a rotating galaxy of standard size, gliding at hundreds of kilometers per second moving in the direction of an unidentified goal in a gigantic Universe, enclosing billions of identical galaxies.

Ultimately, the universe has a wide variety of sized structure and a complex textures; star are gathered into galaxies by the planets that orbit them, clusters galaxies are gravitationally bonded together, while larger superclusters contain clusters of galaxies.

A system with many stars that is dynamically bound is called galaxy (Mo et al.,2010). Galaxies are well-defined, astronomical identities. The universe's greatest collection of stars are called galaxy.

The Hubble sequence, often known as the Hubble tuning-fork diagram, is the morphological sequence of galaxies that Hubble arranged. Galaxies are categorized under Hubble's scheme into four major classes:

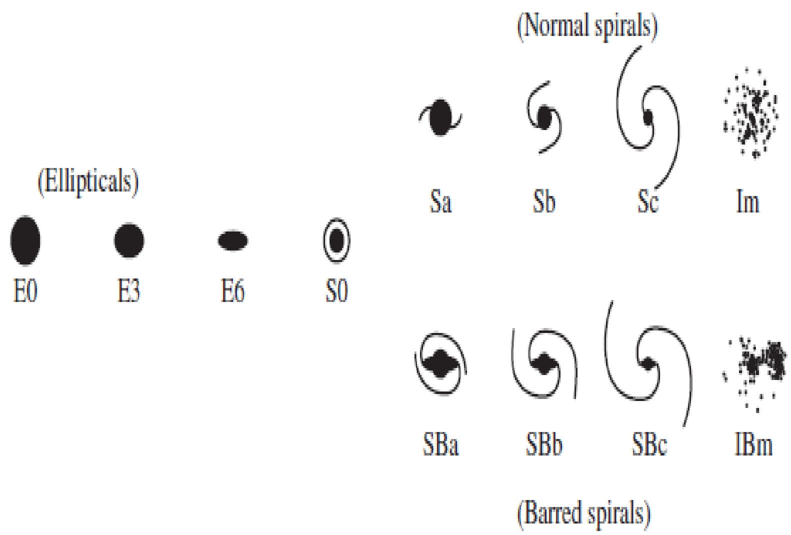

Figure 1: An illustration of the Hubble succession of galaxy shapes (Abraham, 1998)

Barred Galaxies

The most widely accepted explanation states that galactic bars are rotational instabilities caused by density waves that radiate from the galactic core. Through redistributing their courses, these instabilities affect stellar orbits. The altered orbits eventually move outward, resulting in the formation of a bar-shaped self-stabilizing stellar structure (Raha et al., 1991; Sellwood, 2016; Bovy et al 2019; Łokas, 2019; Sanders,2019).

While several examples of twin barred galaxies exist, most barred galaxies consist of a single bar structure contained within the bulge (e.g., Milky Way, NGC 1291, NGC 1326, NGC 1543), in these situations, the smaller secondary bar is encased inside the bigger primary bar (Erwin, 2005; Debattista & Shen, 2006; Du et al., 2016; de Lorenzo-Cáceres et al.,2019).

Additionally, bars have the ability to direct material into the center of the galaxy; this is particularly true for the collisional gas component, which has the ability to flow inward and dissipate energy during shocks (Shlosman et al., 1989; Friedli, & Benz, 1993). A bar is a long, linear, non-axisymmetric star structure found in a galaxy's core (Debasish, & Tanuka, 2021).

Many analyses of the dynamics in barred galaxies have indicated that the gas inside the co-rotation experiences negative gravity torques as a result of the bar, and that it loses angular momentum in a fast central gas flow that moves towards the central kpc or less (Athanassoula, 1992; Sellwood & Wilkinson, 1993).

MATERIALS AND METHODS

Spin Parameter calculation

The spin parameter happens to be the cardinal tangible parameter in verifying the spiral galaxy's physical characteristics.

The spin parameter (Cervantes-Sodi et al., 2013) is given by

$$\lambda = \frac{J|E|^{1/2}}{GM^{5/2}} \quad (1)$$

E is the total energy, J is the angular momentum and M is the mass.

These quantities are not accessible direct observation (Hernandez et al., 2007).

The exponential surface density profile for the disc is

$$\Sigma_D(r) = \frac{M_D}{2\pi R_D^2} e^{-r/R_D} \quad (2)$$

R_D = Characteristic scale length

M_D = total disc mass

$$M_D = \int_0^\infty 2\pi r \Sigma(r) = 2\pi \Sigma_o R_D^2 \quad (3)$$

The total circular velocity of the disk system is

$$V_c^2(r) = V_D^2 + V_H^2 \quad (4)$$

$$V_D^2 = \left({GM_D}/{2R_D}\right) x^2 B\left({x}/{2}\right) \quad (5)$$

$$x = {r}/{R_D}$$

$B = I_0 K_0 - I_1 K_1$ (Modified Bessel function)

Where

Modified Bessel function of the first kind

$$I_n(x) = \frac{1}{\pi}\int_0^\pi cos(n\theta)\, exp(xcos\theta) d\theta$$

$$I_0(x) = \frac{1}{\pi}\int_0^\pi exp(xcos\theta) d\theta$$

$$I_1(x) = \frac{1}{\pi}\int_0^\pi cos(\theta)\, exp(xcos\theta) d\theta$$

Modified Bessel function of second kind

$$K_n(x) = \int_0^\infty cosh(nt)\, exp(-xcosht) dt$$

$$K_0(x) = \int_0^\infty exp(-xcosht) dt \;\; x > 0$$

$$K_1(x) = \int_0^\infty cosht\, exp(-xcosht) dt \; x > 0$$

$$V_H = \left(\frac{GM_H}{R_H}\right)^{1/2} \quad (6)$$

The pattern of angular momentum associated with the center of gravity in the flat galaxy approximation with circular orbits was describe in (Obreschkow & Glazebrook, 2014).

$$J = |\int dMr \times V| = 2\pi \int_0^\infty drr^2\Sigma(r)\,V(r) \quad (7)$$

where V is the velocity vector, r is the position vector from the center of gravity, dM is the mass element, $\Sigma(r)$ is the azimuthally averaged mass surface density of the considered baryonic component, and $V(r)$ is the norm of v at r =| r|.

The specific angular momentum

$$j = \frac{\int_0^\infty drr^2\Sigma(r)V(r)}{\int_0^\infty drr\Sigma(r)} \quad (8)$$

After presuming an exponential disk $\Sigma(r)\alpha\, exp\left(-{}^{r}/_{R}\right)$, specific angular momentum becomes

$$j(r) = \left[2 + \frac{\left({}^{r}/_{R}\right)^2}{1+{}^{r}/_{R}-exp\left({}^{r}/_{R}\right)}\right]RV \quad (9)$$

In the limit of $r \to \infty$, the equation reduces (Romanowsky & Fall, 2012) to

$$j(r) = 2RV \quad (10)$$

There will be satisfaction in the halo density

$$\rho(r) = \frac{1}{4\pi G}\left(\frac{V_D}{r}\right)^2 \quad (11)$$

Having halo profile

$M(r) \propto r$

Disc mass fraction is

$$F = \frac{M_D}{M_H} \quad (12)$$

Anticipated to be approximately ${}^{1}/_{10}$.

Since the halo's potential energy makes up the majority of the galaxy's total potential energy and the halo is a virialized gravitational structure, we can substitute E for $E = \frac{W}{2}$, that is half of the halo's gravitational potential energy.

$$W = -V_D^2M_H \quad (13)$$

Therefore;

$$E = -\frac{V_D^2M_H}{2} \quad (14)$$

Perceiving the disc and halo's specfic angular momenta as being equal (Fall & Efstathiou, 1980; Mo et al., 1998)

$$j_D = j_H \quad (15)$$

$$J = M_Hj_D = M_H2V_DR_D \quad (16)$$

Substituting J, E equation (2.1) becomes

$$\lambda = \frac{J|E|^{1/2}}{GM^{5/2}} = \frac{M_H2V_DR_D\left(-\frac{V_D^2M_H}{2}\right)^{1/2}}{GM^{5/2}}$$

$$\lambda = \frac{2^{1/2}V_D^2R_D}{GM_H} \quad (17)$$

We used equation (17) to calculate the spin parameters of more than ten barred galaxies

Bravais Pearson Correlation

We calculated correlation coefficient between the pair of data, so as to understand the magnitude of the relationships. In determining the correlation we used the Bravais Pearson correlation.

$$r = \frac{\sum(X-x)(Y-y)}{\sqrt{\sum(X-x)^2\sum(Y-y)^2}} \quad (18)$$

Where X = spin parameter of galaxy

x = mean for spin parameter of galaxies

Y = age of galaxy or total mass of galaxy or mass of gas

y = mean for Y

RESULTS AND DISCUSSION

Results Presentation

Table 1: Summary of the results of the spin parameter, total masses, gas masses and some of the age of the galaxies

S/N	Galaxies	Spin Parameter	Total Mass ($M_\odot$)	Gas mass 10^9($M_\odot$)	Age 10^9
1	Milky Way	0.0253	2.3×10^{11}	8.43	13.8
2	NGC 4258	0.8051	3.9×10^{7}	8.1	
3	NGC 3521	0.4074	2.18×10^{11}	4.8	13.26
4	NGC 2903	0.4349	2.10×10^{11}	8.4	
5	NGC 3351	0.1832	1.83×10^{11}	2.8	13.26
6	NGC 3198	0.1869	1.75×10^{11}	10.7	
7	NGC 3556	0.5073	8.73×10^{10}	7.0	13.27
8	NGC 2841	0.1705	1.02×10^{12}	1.9	
9	NGC 224	0.0491	1.5×10^{12}	5.2	10
10	NGC 5055	0.8561	1.4×10^{11}	16.1	
11	NGC1566	0.0624	6.5×10^{10}	17.6	
12	NGC 5194	0.2834	1.40×10^{11}	11.3	0.4003
13	NGC 7331	0.2117	3.8×10^{11} (d)	19.7(d)	

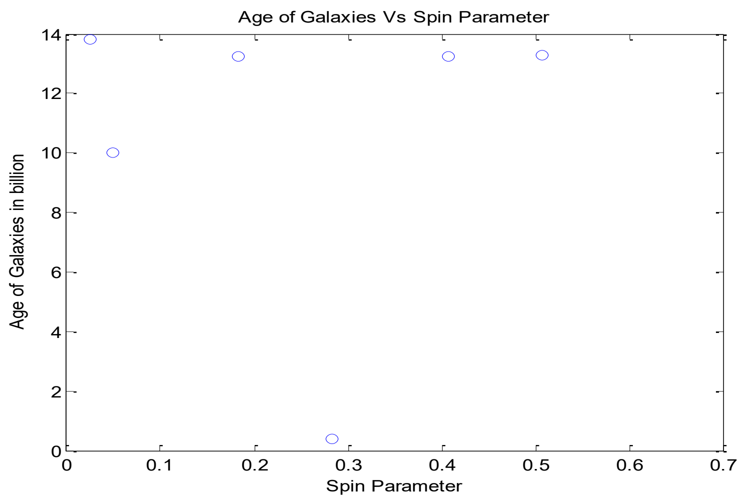

Figure 2: It shows the relationship between the Spin parameter and the age of the galaxy. It's for the raw data

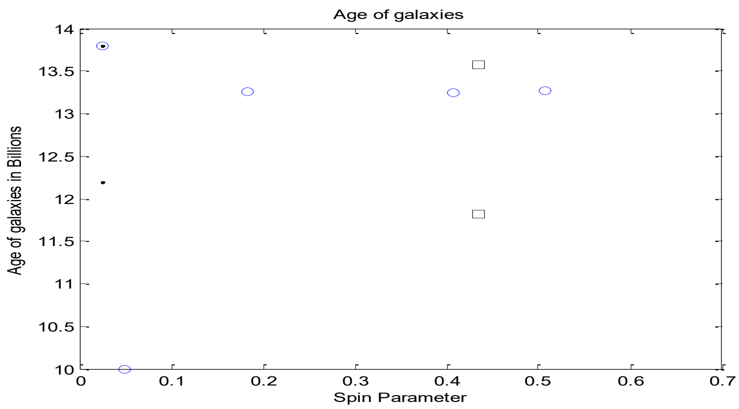

Figure 3: Predicting the age of the NGC 2903 with Spin 0.4349 at polynomial of 3rd and 4th degree

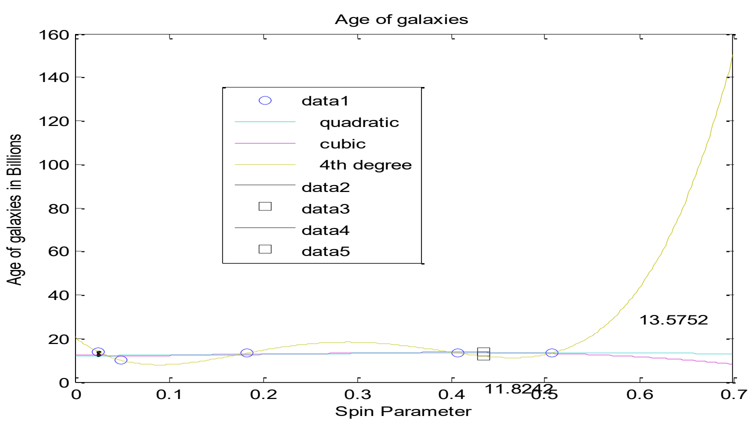

Figure 4: Predicting the Age of NGC 2903 with spin 0.4349. The age at the 3rd degree is 13.5752 billion years and at the 4th degree it is 11.8242 billion years

Table 2: The table show the summary of the result of the spin parameter, total masses, gas masses and the predicted ages

S/N	Galaxies	Spin Parameter	Total Mass ($M_{\odot}$)	Gas mass $10^9 M_{\odot}$	Age 10^9
1	Milky Way	0.0253	2.3×10^{11}	8.43	13.8
2	NGC 4258	0.8051	3.9×10^{7}	8.1	12.63 (this work)
3	NGC 3521	0.4074	2.18×10^{11}	4.8	13.25
4	NGC 2903	0.4349	2.10×10^{11}	8.4	13.58(this work)
5	NGC 3351	0.1832	1.83×10^{11}	2.8	13.26
6	NGC 3198	0.1869	1.75×10^{11}	10.7	12.63 (this work)
7	NGC 3556	0.5073	8.73×10^{10}	7.0	13.27
8	NGC 2841	0.1705	1.02×10^{12}	1.9	12.4 (this work)
9	NGC 224	0.0491	1.5×10^{12}	5.2	10
10	NGC 7331	0.2117	3.8×10^{11}	19.7	12.71(this work)

Discussion

The total mass for galaxies consist of the mass of the disk, bulge, halo and gas, for some of the galaxies the total mass was obtained from literatures together, whereas for others the masses for the different components were found and then added together.The mass of gas for each galaxy was obtained from different literatures In predicting the ages for the remaining five galaxies, rigorous work was done using polynomial of varying degrees and writing scripts using MATLAB. The correlation was calculated using equation (18). The correlation between the spin parameter and the mass of the galaxy is $r = -0.553$. It has a negative high correlation. The correlation between the spin parameter and mass of gas is $= 0.209$. The correlation is low. The correlation between the spin parameter and the age of the galaxy is $r = 0.377$. The relationship is low also. The correlation between the spin and the age of the galaxy was found to be high but that of the total mass and mass of gas was low. Using the a sample of polynomial from MATlab predication of the age of the galaxy, total mass and mass of gas was made.

CONCLUSION

The spin parameter was calculated using $\lambda = \frac{2^{1/2} V_D^2 R_D}{G M_H}$ and MATLAB was used to write a script in order to avoid too much error. The spin parameter was calculating by imputing the values for the rotational velocities, scale radius, halo mass for each of the galaxies because they all have different values. The following results were obtained: Milky Way galaxy is 0.0253, Andromeda is 0.0491, NGC 4258 is 0.8051, NGC 3521 is 0.4047, NGC 2903 is 0.4349, NGC 3351 is 0.1832, NGC 3198 is 0.1869, NGC 3556 is 0.5073, NGC 2841 is 0.1705 and NGC 7331 is 0.2117. The predicted ages for the following galaxies:NGC 4258, NGC 2903, NGC 3198, NGC 2841 and NGC 7331 are 12.63, 13.58, 12.65, 12.4 and 12.71 billion years respectively.

The correlation coefficient between the spin parameters and ages was calculated using Bravais Pearson correlation and was found to be 0.377. The correlation is low, that means the age has little effect on the spin parameter. The correlation coefficient between the spin parameters and total mass is - 0.553. It has a high negative correlation. Which means that the spin parameter is increasing in opposite direction as the mass is decreasing. The correlation coefficient between the spin parameters and mass of gas is 0.209. The correlation is low. That means that mass has very little effect on the spin parameter.

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