Trinity College Dublin

# NGC 3034: The Cigar Galaxy

Alexandra Mulholland
17336557
Prof. Jose Groh

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# Contents

# Abstract

A profile of galaxy NGC 3034 was produced using numerous literature sources regarding the fundamental and supplemental properties. NGC 3034 is an irregular-dwarf starburst galaxy, which has undergone gravitational interactions with neighbouring galaxy NGC 3031. This interaction has resulted in the high rates of star formation, and the once spiral galaxy is now considered a truncated bulge. It is located at right ascension $09^h 55^m 52.725^s$ and a declination value of $69^d 40^m 45.78^s$, with an average distance value of 3.835Mpc. Its distance has been initially determined using the Tully Fisher relation, but upon progression via the Hubble Telescope and increased knowledge on distance determination, the TRGB is now used to determine the distance to be 3.89Mpc. This is seen as a more representative value for NGC 3034 as this galaxy's dynamics makes it an anomaly on the Tully Fisher relation. The inclination angle of 77˚ makes the central morphology of this almost edge-on galaxy difficult to investigate, meaning the discovery of a central bar (of 1kpc length) and spiral arms was relatively late during examination of NGC 3034. The total dynamical mass of NGC 3034 is approximated to $\sim 10^{10}$M$_\odot$, with the inner radius 0.5kpc making up $2 \times 10^9$M$_\odot$ of this mass. The observation of the kinematic properties of planetary nebulae allows the examination of a rotation curve, which indicates no effect of dark matter presence. The lack of dark matter is hypothesised to be due to the interaction of NGC 3034 and NGC 3034, from which the dark matter was stripped. The presence of an AGN is still under scrutiny, but from current resources, the suspected AGN is most likely SNRs. Of recent interest is the supernova 1a event in 2014, which provides a new source of distance determination and knowledge of the regions in which the supernova occurred.

## 1.1 Discovery

First discovered by Johann Elert Bode in 1774, the galaxy known as NGC 3034 in the New General Catalogue is also referred to as The Cigar Galaxy. It has been observed and studied on countless occasions and contains upwards of 30 billion stars. This galaxy is also referred to as Messier 82 galaxy, catalogued by Charles Messier in 1781- alongside the spiral galaxy M81, which was discovered on the same night and named Bode's galaxy.

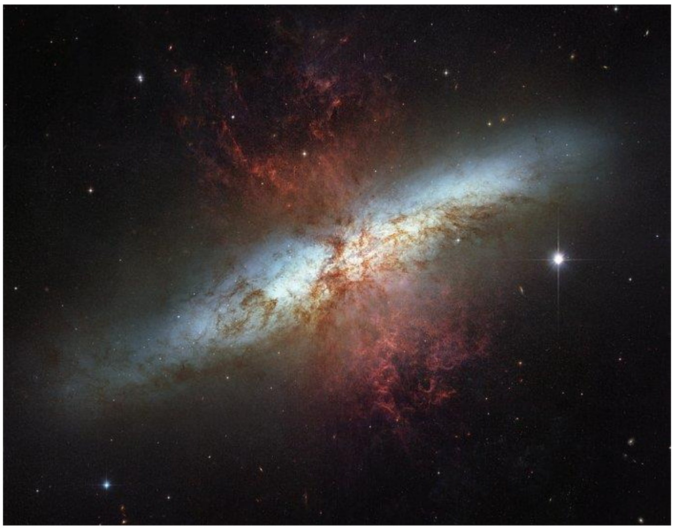

Figure 1.1 Image of galaxy NGC 3034 in the visible spectrum through a series of filter exposures. The plumes of red hydrogen are evident in this image (explained later in further detail).

## 1.2 Classification, Morphology and Structural components

NGC 3034 is viewed edge-on, appearing as a 'cigar' shaped galaxy. Position classification by the Modern Equatorial Coordinate system gives a right ascension value of $09^h55^m52.725^s$ and a declination value of $69^d40^m45.78^s$. [1]

Upon initial discovery, the galaxy was classified as irregular, more specifically by de Vaucouleurs in 1959 as IO [5], meaning it is completely random and perhaps chaotic in nature. Then in 1979 by Sandage & Brucato as amorphous, meaning it has no spiral feature but an unresolved disk. However, observations through the analysis of near-infrared images revealed 2 distinct spiral arms in 2005, with a disk of length of 825 pc (as observed in the K band)[3] and, in a study conducted in 1991, a central bar of length 1kpc [40]. However, this investigation was found to be largely inconclusive, due to the edge on nature of NGC 3034. This edge-on orientation further hindered the conclusion of the presence of spiral arms, as stated by (Mayya et al.), who attributed the lack of detection to the galaxy's orientation (77˚ inclination angle), high disk surface brightness and exceptionally high levels of dust and gas present in optical images. The discovery of spiral arms[6](Figure 1.2), however, lead to the categorisation of NGC 3034 as a somewhat spiral galaxy, whose disk has become heavily distorted. Upon further observation of the core being an intense radio wave source, it is now more commonly described as a starburst galaxy- one which contains an exceptionally high number of star-forming regions. As explained later in section STAR FORMATION, there is thought to be large amounts of gaseous infall within the galaxy [27]. [8] (Mayya, L. Carrasco et al.) carried out detailed simulations identifying the cause for gaseous infall to be related to the formation of a bar and/or spiral arms. These morphological features may help attract the gas towards the central regions. This would imply the identification of a bar is correct, as it agrees with the current dynamical nature of NGC 3034.

Currently, it is identified as a dwarf irregular-disk starburst galaxy- dwarf due to its relatively low mass ($\sim 10^{10}$M⊙) [18]. Both this and the disk distortion has been found to be a product of the gravitational interaction occurring between the two galaxies (M81 and M82), forming a physical pair [4]. The initial shockwave sent through the clouds of gas and dust causes their collapse, subsequent tidal interactions are thought to create substantial amounts of gas and dust, forming intense star forming regions. (More in sections 3 and 8)

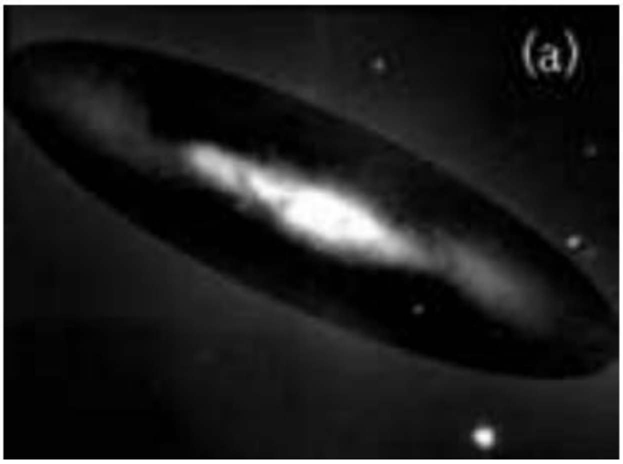


Figure 1.2 of the residual image. The central bright regions indicate the presence of a bar, and the outer structures are spiral arms.

Consequently, when viewing the galaxy through X-ray, one observes large amounts of X-ray emission in the form of galactic winds. Newly formed stars eject enormous amounts of material to produce stellar winds of glowing hydrogen, furthermore, these newly formed stars are relatively short lived. This means supernovae are not uncommon in NGC 3034. This results in the bicone structure, which also contains large amounts of HI gas, as observed by (Martini et al.)[16]. Here, the orientation of NGC 3034 proved advantageous upon studying this outflow along the minor axis (which they did by 10kpc Southerly and 5kpc Northerly direction). There is a significant decrease in the velocity of the H1 gas, from 120kms$^{-1}$ to 50kms$^{-1}$ in the distance range of 1.5kpc to 5kpc off the midplane. This dramatic decrease- which is concluded by (Martini et al.) to prevent the gas from leaving the halo of NGC 3034- cannot be attributed to mere cooling of the gas, nor to the gravitational effects of the central region of the galaxy. Thus, another force must be contributing to the cause of this deceleration. This is hypothesised to be the drag caused by the immediate surroundings of the HI gas.

## 1.3a Distance

According to the data compiled in NED for redshift independent distances, the average value for the distance to this galaxy over 21 studies was found to be 3.835Mpc. Early studies utilise the Tully Fisher method, and as a result overestimate the distance value, being around 5Mpc. In the late 1990s and early 2000's, as explained below, the average distance values were calculated to be ranging from 3.2 to 3.9 Mpc. Finally, as explained in section 8, following the 2014 supernova discovery in NGC 3034, SN 2014J was used to calculate distance.

NGC 3034 is within what is called the Local Volume, which is the region of space around the Milky Way, extending to 10Mpc. Before the early 1990s, the observed cosmology of this Local Volume was hindered by the lack of data and resources to measure such distances, despite this galaxy being the closest starburst galaxy to us. However, the Hubble Space Telescope's variety of capabilities and a greater selection of distance-determining techniques at our disposal has made the measurement of such distances to be carried out within a 5-10% accuracy. [15]

Many estimates of the distance to NGC 3034 have been approximated as the distance to the galaxy group M81 (see section 1.4) as M82 is a member of this group. This distance has been calculated using Cepheid variables located by the Hubble Space Telescope. These cepheids had periods ranging from 10 to 55 days, and the distance was found to be 3.63 ± 0.34 Mpc by (Freedman et al.) in 1994.[2] They report a distance modulus of $(m - M)_0 = 27.80 \pm 0.20$ mag, which, using the formula (1) $m - M = 5\log\left(\frac{d}{10pc}\right)$, results in said d value.

Due to the so-called peculiar nature of galaxy NGC 3034, it is difficult to use standard methods to determine its distance from us. A study conducted in 1999 by Sakai & Madore utilised one of the relatively newer distance-determining techniques known as TRGB[17], the Tip of the Red Giant Branch. This technique utilises the lifecycle of Red giants (shown in the Hertzsprung-Russell diagram), which are abundant in the stellar population of NGC 3034.

The stars being investigated have used up all the hydrogen in their core and hence form a core of helium, supported by the quantum mechanical movement of the electrons, with a hydrogen burning shell surrounding this core. This creates a helium 'snow' falling into the core, making it larger and larger in mass, but smaller in radial size- and so it is denser. There is a maximum size that a core supported by this quantum-mechanical degeneracy pressure can reach. Therefore, the electrons must move faster and faster to support it all, to a point where they reach almost the speed of light and can no longer support this core. The core then shrinks to the point where groups of three helium atoms combine to form carbon, therefore the helium has been ignited, otherwise known as the "helium flash" of old, low-mass stars progressing up the red giant branch. This burning creates a huge amount of energy, whereby the star rearranges itself to form a red giant. At this point, it moves off the red giant branch to the horizontal branch. This sudden transformation will happen at a very precise mass.  This is seen as a discontinuity in a colour-magnitude diagram where there are many stars until the point of the tip of the red giant branch, and then a significant lack of stars. Sakai and Madore utilised this method [17] and found a relatively similar distance to M82 as accepted values. They observed two regions in the halo of NGC 3034, using the Hubble Space Telescope and the Wide Planetary Camera. The detected the Red Giant stars and used the I-band luminosity function to determine the galaxy's distance. (Sakai et al.) found the discontinuity to be at an absolute magnitude of approximately -4 magnitudes in the I band. They identified the method to be most effective when the I-band luminosity function sample is restricted to the stars in the halo region only, due to lack of both crowding and internal extinction. Determining the TGRB distance modulus to be (m-M)=27.95 mag, they found the linear distance to the galaxy NGC 3034 to be 3.89Mpc using formula (1).

The sources of error, which may have resulted in this slightly higher average than most, were the random uncertainties in the tip of the red giant branch position, and systematic uncertainties due to TRGB calibration, which is performed using RR Lyrae distance scale.

1.3b TULLY FISHER

As mentioned, the unconventional nature of this dwarf irregular disk galaxy makes it difficult to determine the place of NGC 3034 on the Tully Fisher relation. The presence of spiral arms [3] means NGC 3034 can be loosely described to fit on the Tully Fisher relation. (Igor D. Karachentsev et al.) published a paper in 2016 regarding the Tully Fisher relation for Dwarf galaxy. [25] They plotted the graph for K-band luminosity versus line width. This line width was that of HI at 50% of the peak HI flux and is indicative of the rotational velocity of the gas. Figure (1.3a,b) shows the trend for 206 galaxies in the local volume, with galaxy NGC 3934 (M82) indicated. One can see that while it may roughly follow the trend, it may be an anomaly for this Tully Fisher relation. Figure 1.3a shows the logarithmic function of the luminosity versus the observed line width ($W_{50}$), while figure 1.3b shows the line width corrected for the inclination of the galaxies ($W_{50}^{c}$). We see this figure has less dispersion in the data set. Parameters $\beta$ and $\sigma$ in corners show the regression slope and dispersion.

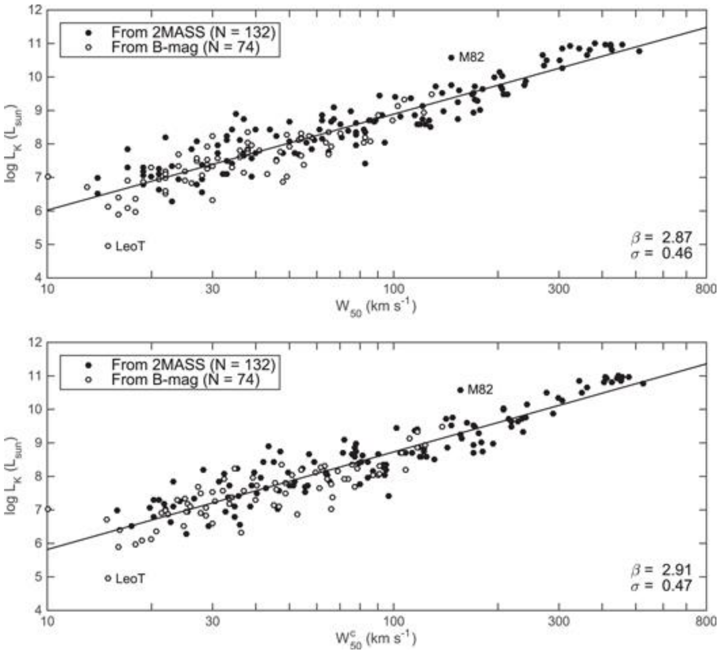


Figure 1.3a and b showing the position of NGC 3034 on the Tully Fisher relation of luminosity versus HI line width.

An interesting remark is that shown in Figure 1.3c, whereby the logarithmic K band luminosity is plotted against the morphological type of the galaxy (indicated by a value of de Vaucouleurs numerical type T). NGC 3034 is of numerical type equal to 8, indicating it is somewhere between a spiral and irregular galaxy. The mean values in the graph are indicated by circles, and the standard deviation indicated by rectangles. NGC 3034 is clearly uncharacteristic for dwarf galaxies again- showing an unusually large luminosity for its numerical type.

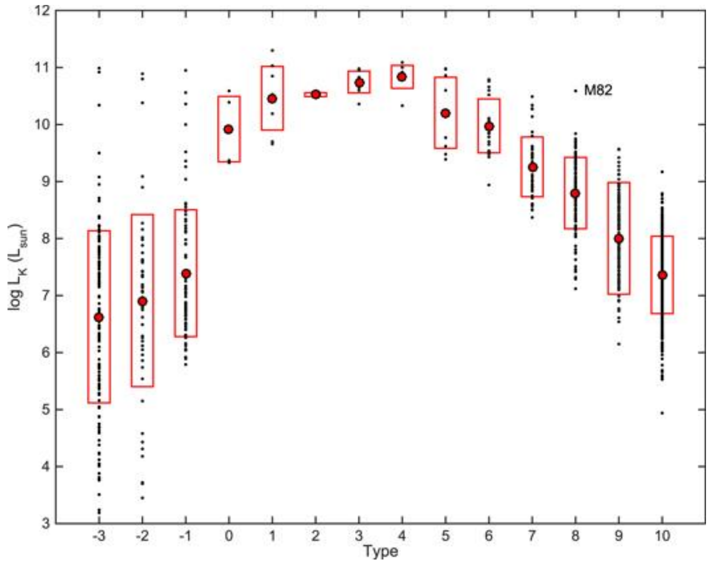


Figure 1.3c: Plot of the luminosity in the K band versus de Vaucouleurs numerical type T.

## 1.4 Presence in a group

NGC 3034 appears to be in the constellation Ursa Major, as seen from our vantage point on Earth.

The group of galaxies in which NGC 3034 is contained is known as the M81 group, consisting of 2 Messier objects (M81-NGC 3031 and M82-NGC 3034). Other members of the group include NGC 2976 and NGC 3077. [11] The elliptical galaxy NGC 3077 has also been gravitationally disrupted by neighbouring galaxies NGC 3034 and NGC 3031, as shown in figure 1.4a, where there is clearly a common gaseous engulfment. NGC 2976 is an unbarred spiral galaxy, also distorted by gravitational interaction with M81. These are just 4 members of the 34 galaxies within the group.

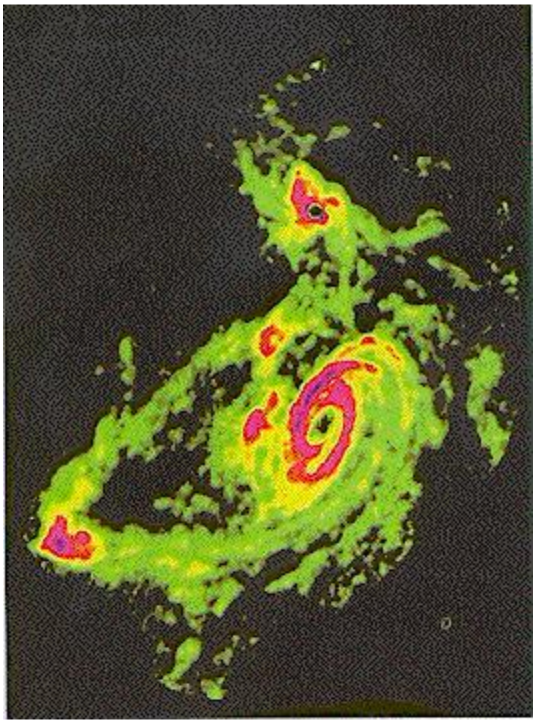

Figure 1.4a: [11] Radio image of interacting members of the M81 group. NGC 3031 is the spiral located centrally, NGC 3034 above NGC 3031 and NGC 3077 in the lower left.

However, (I. D. Karachentsev et al.) based their findings o the number of galaxies allocated to this group in the year 2006, which was 29 galaxies. [9] They calculated the Virial mass estimate for group M81 to be 1.17 x 10^12 Msun. [10] (Nizhniy Arkhyz et al.) in 2004 estimated the radius of the M81 group to be 0.89Mpc, and from this, obtained the mass of the group to be 1.03x10^12Msun. After which, they concluded the masses of the two brightest galaxies in the group (M81 and M82) to be 6.7x10^11Msun and 3.6x10^11Msun respectively, assuming a Hubble constant of 72km/s.

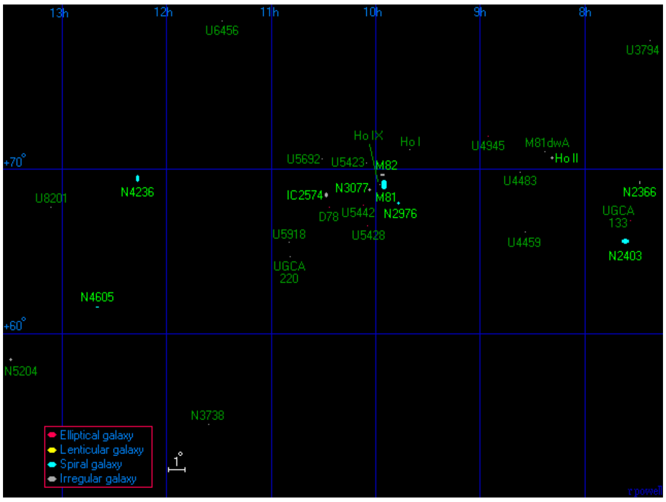


Figure 1.4b showing the positions of each galaxy in the M81 group.

## 2 Dust properties

It has been expressed how difficult the morphological and dynamical components of NGC 3034 have been to acquire, and how the orientation and large amount of extinction, a combination of absorption and scattering, is responsible for such difficulty. For instance, the presence of O-type stars within the central clusters of NGC 3034 emit blue light, but this is not apparent due to interstellar reddening. By probing the behaviour of the extinction law (the variation of extinction with wavelength along each line of sight), one can infer the properties, such as size and chemical composition, of the dust grains in the interstellar medium of NGC 3034.

The extinction, which causes interstellar reddening, becomes more apparent in the presence of smaller dust grains. The similarity of photon to dust grain size induces higher levels of scattering, synonymous to the diffraction effect. Interstellar reddening is just that, the appearance of a galaxy appearing more red than it would, had there been no extinction effect. This is the result of the dust presenting an effectively larger cross-section to blue light, which has a shorter wavelength than red light, and so is scattered more heavily, while red light passes through. Remarkably, [24] (Susan Hutton et al.) investigated the absorption features which appear in the light spectrum of NGC 3034, and found a presence of what is known as the 2175 Angstrom bump. This was noteworthy as it is highly uncommon amongst star-bursting galaxies. This is due to the clumped dust in starburst galaxies, where there is usually a dust free, high star concentrated core, and a star-free dust surrounding this core. Another explanation for such a feature is the metallicity of region- whereby a lower metallicity value results in the absence of this bump. From these results, it can be concluded that this is not the case for NGC 3034, for which the dust and stars may not be spatially distinct, or NGC 3034 has higher metallicity values than expected for starburst galaxies. (Hutton et al.) examined UV light patterns in NGC 3034. This light is apparent from the central regions of NGC 3034, where there is a high volume of star formation, and reveals dust present in the super-wind.

This examination was conducted prior to t the supernova event in 2014 (explained later), and by doing so, can determine the progenitor system of this event. They find the area around which the supernova occurred is comparable to the Milky Way, with a standard dust component. They find the UV bump weakens with distance from the galactic centre, away from the central starburst. Here dust grains are smaller and in lesser volumes. The ratio of total to selective extinction is used to determine the concentration of dust- a value around 3.1 indicates a relatively diffuse ISM, which was the result when analysing the central region of NGC 3034.

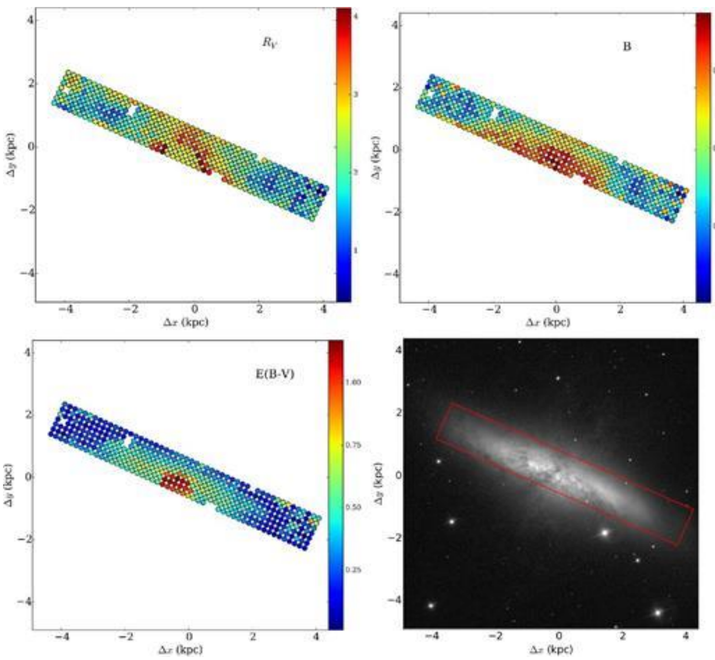


Figure 2: Colour image diagrams

The colour diagrams shown in figure 2 indicate the relative strengths of the ratio of total-to-selective attenuation and UV bump. It is worth noting that these figures are of two-dimensional distributions include both the star-bursting and outer regions.

## 3 Star formation

Within the core of M82, a 2005 Hubble Space Telescope image revealed 197 large clusters of young stars in the central region of NGC 3034. Within the core alone, the star formation rate is approximately 10 times faster than that of the whole Milky Way galaxy. This makes NGC 3034 the strongest source of radio emissions in Ursa Major, and one of the most luminous galaxies viewed in the infrared ($L_{IR} = 3 \times 10^{10} L_\odot$) [4]. Its proximity and high infrared luminosity allow for detailed analysis of star formation within NGC 3034.

Figure 3a: Image of NGC 3034 pictured in the infrared.

(Igor D. Karachentsev et al.) [14] investigated the star formation rates for 802 galaxies within the Local Volume region. Using images of the flux of Hα and Far UV surveys, the figures shown below indicate the ratios of the star formation rates using the ratios of these fluxes. Figure 3b shows the ration dependence on the B magnitude of each galaxy. Bursts of star formation are evident in the lowest mass dwarfs, whereby the scattering of the star formation rate ratios increases with decreasing luminosity of the galaxy. Galaxy NGC 3034 is indicated, labelled M82, and is an example of this due to the large amounts of star formation bursts in the central regions. Because the star formation rate in a galaxy determined by the Hα flux is on a short timescale, and is indicative of young and hot O- type stars, the position of M82 tells us there is approximately 10 times more O-type stars than B type stars (which are indicated by the far infrared flux). This can be analysed from the log of the ratios being approximately equal to 1. This is an expected result for NGC 3034, where O-type stars are common in intense star formation regions of irregular and spiral galaxies.

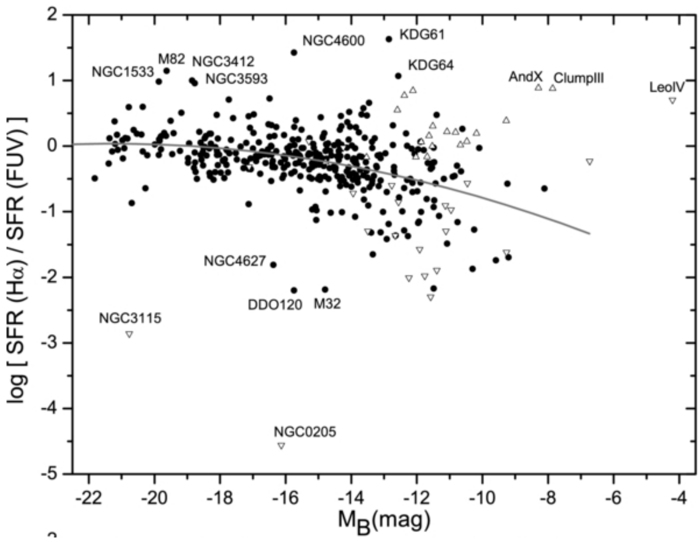


Figure 3b showing the star formation rate ratios versus the B magnitude of 802 galaxies in the LV. NGC 3034 is shown.

[18](Greco et al.) Utilised the CO band absorption line width to determine the rotation, as mentioned in section MASS DISTRIBUTION. By measuring the line width as a function of distance from the centre of the galaxy, they were able to deduce the spatial extent of the Red Supergiant population. In contrast with (Karachentsev et al.), they found Red Supergiants to dominate the region within 0.5pc. Again, due to dust attenuation, one can argue that this distance is such that there could be a distinction between the O-type and K-type stars within the region. This was highlighted by (de Grijs et al.) [27] who determined the bright infrared sources associated with starbursts are constricted to within a 250pc radius of the NGC 3034 centre.

(N. M. Förster Schreiber et al.) determined the starburst activity within NGC 3034 occurred in two successive periods, each with a duration of a few million years. The first occasion took place $10^7$ years ago and occurred throughout the central regions of NGC 3034. The second occasion took place $5 \times 10^6$ years ago and occurred in what they referred to as the "circumnuclear ring" and along the stellar bar [26]. In agreement with previous studies, this can be interpreted as being a direct result of the gravitational interaction between NGC 3034 and NGC 3031, followed by a "bar-driven" evolution.

Present-day NGC 3034, with a high star formation rate of $\sim 10\ M_{\odot}\ yr^{-1}$ , has been attributed to the combined effects of infall of disrupted debris from the outer regions of NGC 3034 onto its disk, along with star formation, dependent on this debris, in the active core propagating on a large scale. [27] (de Grijs et al.) used a B-band image of NGC 3034 (Figure 3c) and identified the highest surface brightness regions as M82 A and M82 C, which are less than 50Myr old. M82 B, also labelled, is an older starburst region less than 100Myr old, and M82 F and L are clusters of stars.

Again, M82 A and C demonstrate strong Balmer emission lines, and therefore are indicative of O-type stars.

Around 110 compact, young star clusters have been identified in B, with absolute magnitudes ≤-9. The average age for the stars in this region is around 650Myr, although 22% are older than 2Gyr.

Cluster F, of absolute magnitude $M_V \sim -16$mag is located 440pc from the centre and around 60Myr in age. Its approximated mass is 1.2x10^8Msun- exceptionally massive for a single star cluster. The mass of cluster L has a similar age estimate, although is highly reddened from dust obscurity.

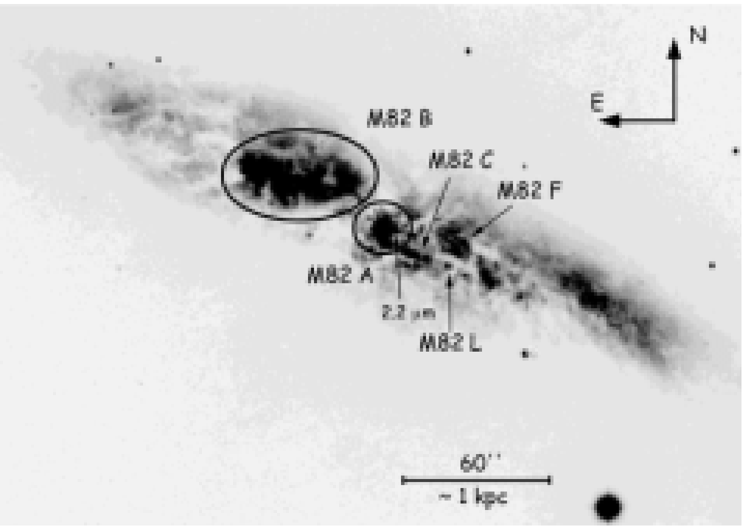


Figure 3c: B band image of the bright regions of NGC 3034.

From high strength of the Balmer absorption lines and a large Blamer discontinuity, the region M82 B, which is between 400 and 1000pc from the centre of NGC 3034, we know is dominated by hot early A-type stars. The Balmer discontinuity results from electrons within the hydrogen atom absorbing photons of energies which allow them to escape the second energy level to the continuum of the Balmer series of hydrogen.

The starburst core also contains supernova remnants, which are less than a few hundred years old, based on there structures and evolution. This reconfirms the view of the centre being drastically younger than regions at larger radii.

## 4 METALLICITIES

The likely range for the metal abundances of NGC 3034 is 0.4 to $1.2Z_{\odot}$. It has been discussed that supernovae ejecta create a feedback process for future stellar populations within NGC 3034. The material ejected is therefore likely to have higher metallicity values relative to early stars. However, [19] (Umeda et al.) observe the X-ray emissions from NGC 3034 and find particularly high levels of Silicon and Sulphur relative to oxygen and Iron, shown in figure 4. From these observed emission lines, evidence for Ne and Mg were also found. This unbalanced chemical composition cannot merely be explained by the presence of type 1 and type 11 supernovae. The authors suggest the occurrence of hypernovae- Star deaths which can produce more than 100 times more energy than a supernova and occur in stars 5-10 times more massive than the sun. It is likely that these could be the red giant population, which can be up to 10 times the mass of the sun and live to 2 billion years, exploding in this way.

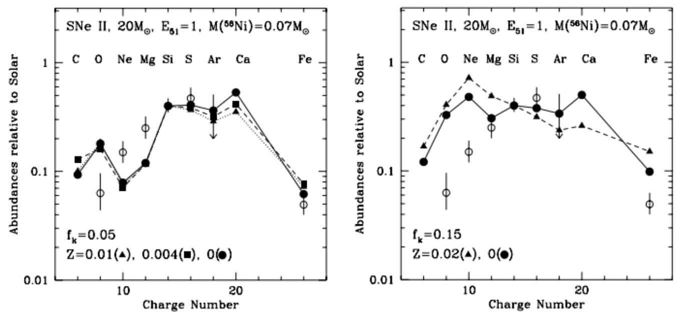


Figure 4 showing the abundance patterns in the ejecta for supernovae II of mass 20Msun, compared with the observed abundances of NGC 3034. The open curcles with error bars indicte NGC 3034 data. The lesser O abundance is evident in both figures.

## 5 KINEMATICS and lack of DARK MATTER

Fascinatingly, studies into the rotation curve of NGC 3034 highlight almost a complete independence of the effects of dark matter. [16] (Paul Martini et al.) analysed the HI kinematics along the minor axis of NGC 3034. Analysing this gas along the minor axis has many 2 major advantages: the orientation of NGC 3034 allows for easy analysis of the minor axis and the abundance of neutral gas clouds within this galaxy means many photons are continuously being emitted, due to electron flipping its spin within the H atom- thus moving down to a lower energy level and emitting a photon in the process. The 21cm line produced allows us to infer its presence.

Arguments have been made as to the galaxy NGC 3034 as being a “disk-truncated bulge” [7], based on the rotation curve produced, which showed a steep rise, with a peak at radius value 200pc. It then declines following a Keplerian fashion. (Yoshiaki Sofue et al.) theorised this structure based on the trend of rotation curves for central bulges of high stellar mass concentration spiral galaxies. The decline in the rotation curve suggests a lack of extended disk mass. Before analysis of NGC 3034, no galaxy had ever demonstrated a Keplerian rotation curve within a few kpc. Here, it was assumed the distance to the galaxy is 3.25Mpc.

An “envelope-tracing” method was applied in order to obtain the rotation curve. The result is presented in figure 5a of rotational velocity versus the radius as the thick line. The dotted line shown here represents the HI rotation curve, obtained by the intensity-averaged velocity of this gas.

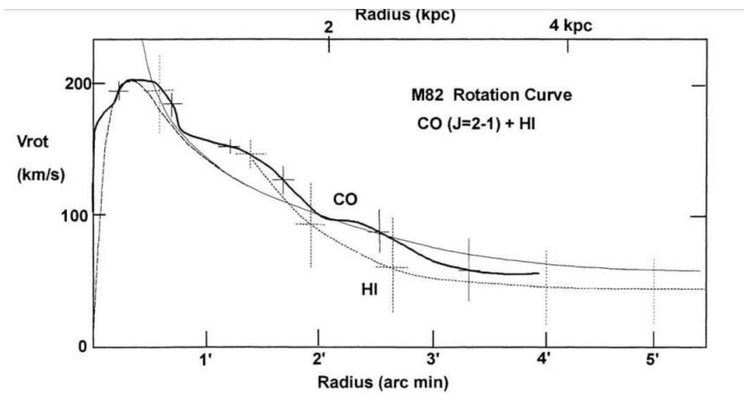


Figure 5a showing the rotation curve for NGC 3034.

To represent the significance of this discovery, the rotation curves of the Milky Way and NGC 3031 galaxies are plotted with NGC 3034 for comparison. The result is shown in figure 5b. It is clear the rotation curve declines to a velocity of 50km/s at a radius of 4kpc. The orientation of the galaxy allows us to dismiss the possibility of the warping of the flat rotation disk, as this would be visible in images of this edge-on galaxy. Figure 5c also compares the rotation curve to 37 nearby galaxies, further emphasising the complete lack of a flattened rotation pattern.

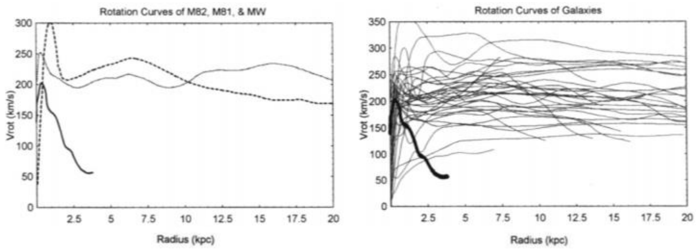


**Fig. 3.** Rotation curve of M82 (full line) compared with those of M81 (dashed line) and the Milky Way (dotted line), as well as with those for other spiral galaxies (thin lines).

Figure 5b and c: Rotation curve of NGC 3034 compared with NGC 3031 (dashed) and the Milky Way (dotted line). Rotation curve of 37 nearby galaxies compared with NGC 3034. Both sets of axes show rotational velocity versus radius.

Here, it was deduced that this pattern is consistent with the rotation curve of the central bulge of a massive galaxy such as the Milky Way. It was assumed the disk has been truncated by a tidal force from NGC 3031.

[3] Johnson et al. analysed the kinematics of 109 planetary nebulae present in NGC 3034 and found the systematic velocity of the galaxy to be 200km/s, with a velocity dispersion of 60km/s. Figure 5d shows the receding side of the disk (which has positive offset) is redshifted to greater velocities than the systematic velocity. While the approaching side of the disk is blueshifted.

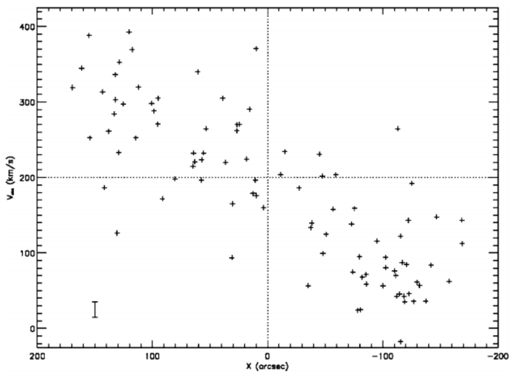


Figure 5d showing the velocities of the planetary nebular sample against their distance along the major axis from the centre. The top left panel indicates the approaching component of the galaxy.

Due to these results, the history of the kinematics and morphology of the galaxy was deduced to be the following ” [7]:

The tidal interaction between NGC 3031 and NGC 3034 left these 2 messier objects along with two other M81-group galaxies, NGC 3077 and NGC 2976, engulfed in a large HI gas envelope. NGC 3034 and NGC 3031 are linked by a tidal HI bridge. The distortion of NGC 3031 extends to the halo of NGC 3034. The amount of molecular gas is substantially larger than would be expected upon consideration of the small total mass of NGC 3034. This large molecular gas mass is hypothesised to be the result of intense star-formation. Thus, it is thought that NGC 3034 was once a larger spiral galaxy, with HI gas in the outer disk and molecular gas in the central region. Upon the encounter of the two galaxies NGC 3034 penetrated galaxy NGC 3031's disk, causing its other disk to be tidally shortened, leaving only the bulge and nuclear disk. The HI envelope and tails we see presently are possibly the remnants of the truncated disk. The density of the central region of NGC 3034 was dense enough to strip away NGC 3031's gas disk, accreting in the centre of NGC 3034. This produced the starburst regions in NGC 3034, leaving NGC 3031 to evolve with little molecular gas in the centre. The interaction has been suggested to have stripped NGC 3034 of its dark matter, meaning this shortened galaxy demonstrates an atypical rotation curve.

## 6 MASS DISTRIBUTION

(Yoshiaki Sofue et al.) [7], as explained later, utilised HI and CO emission lines to deduce the mass of the galaxies NGC 3034 and NGC 3031. The bulge mass was calculated to be 2x10^9Msun. [18] It is estimated that 30-40% of the mass of NGC 3034 is contained within the interstellar medium, with a mass ratio of H2 to H1 of 10:1. As explained [8], this fraction may be due to the large amount of infalling material contributing to the available reservoir. For the sake of simplicity, the authors assumed circular motion to calculate the enclosed mass at each point as, while this is certainly not the case for the central regions (particularly the bar feature), the assumption is valid for estimates on a large scale. Figure 6a demonstrates their methodology: using two slit positions through a K band filter, designated as M82E and M82W (Representing Easterly and Southerly directions). These slits were used to measure the rotation curve out to 4kpc from the centre of NGC 3034.

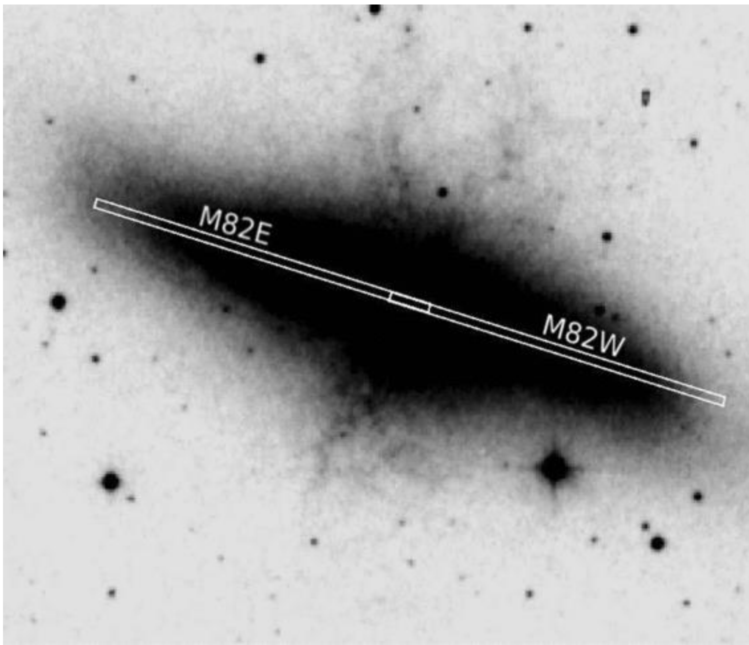


Figure 6a: Location of 2 slits M82E and M82W through a K band filter.

The kinematic measurements taken through these two slits were then used to create a mass profile of NGC 3034, as shown in figure 6b. The limit of 4kpc shows the dynamical mass asymptotically approaching 10^10Msun. In agreement with previous papers, this was deduced to be the total mass of NGC 3034. (P. Greco et al.) [18] acknowledge that within the central regions of the galaxy, circular motion is a poor assumption to determine mass, and thus may be the cause of the apparent decreased mass within shorter radii. The presence of a bar will affect the otherwise circular motion due to streaming of the gases present along said bar. Accepting the uncertainties associated with this assumption, the mass within 0.5kpc was determined to be ≤2x10^9 solar masses, and within this region is thought to be the source of this prodigious outflow known as the super wind- originating from supernovae (releasing ejects) and newly formed stars (producing stellar winds). The material within these winds is preferentially metal-rich to the products of the supernovae ejecta. [16] This creates what is known as a feedback process which regulates star formation: The ejecta provide materials for subsequent stellar generations should it escape to the interstellar medium. Otherwise it may be re-accreted, as described previously, onto the disk.

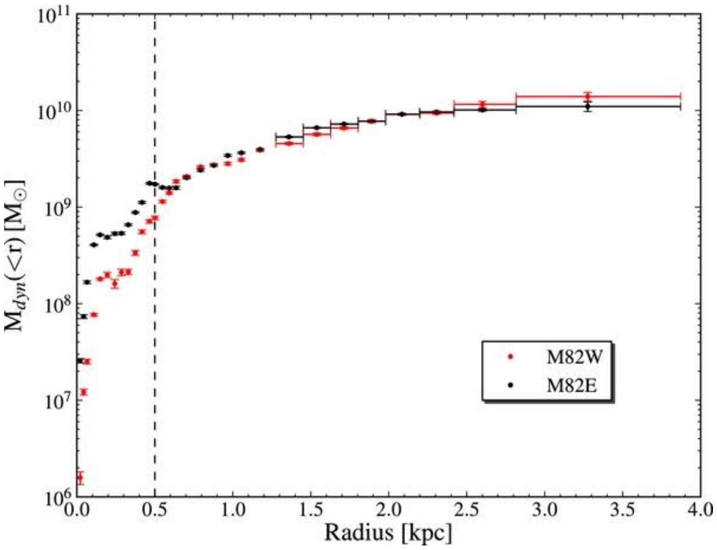


Figure 6b: Plot of the dynamical mass in solar masses versus the radius in kiloparsecs. The mass profile is plotted from the measurements through slits M82E and M82W.

[16] (Paul Martini et al.) also performed a mass model further basing this model off stellar surface photometry and simulations of galaxy NGC 3034 interactions with NGC 3031. They found results in agreement with (Greco et al.) for the mass of the bulge component, being 2x10^9Msun, and further deduce that old stellar populations are not responsible for this mass, as they would be in classical bulges, but rather young supergiants and atomic and molecular gas. They find the disk component to be the most prominent out to around 2kpc. Their model is shown in figure 6c, where the similarities with figure 6b are evident.

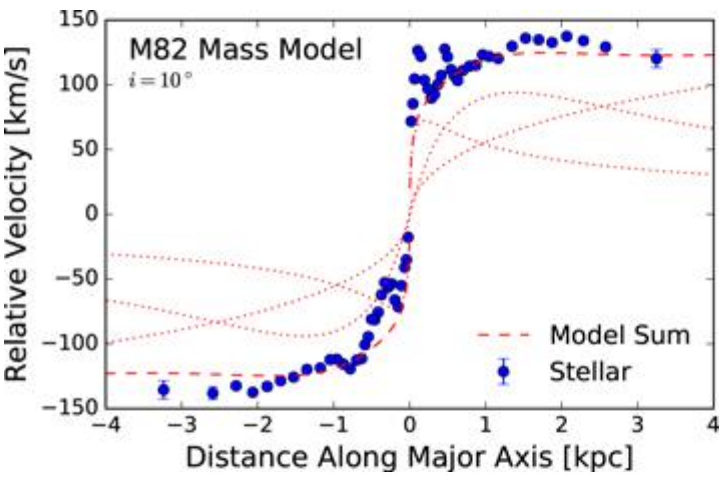


Figure 6c The (Martini et al.) mass model for NGC 3034.

## 7 PRESENCE OR ABSENCE OF AGN

Newly formed O- and B-type stars occur in large clusters in the core of NGC 3034. The dynamics of this galaxy means it has been analysed using X-rays on numerous occasions.

[12] (Hironori Matsumoto et al.) identified three components upon observing NGC 3034 upon utilising the ASCA (the Advanced Satellite for Cosmology and Astrophysics- It is the first X-ray astronomy mission which combines imagine with good spectral resolution, a broad range of wavelengths which can pass through the filter and large effective area). The components identified were soft (low energy), medium and hard (high energy) within the ASCA spectrum. The soft and medium components are highly extended and so are believed to be driven by the stellar winds of massive stars and supernovae, as they show emission lines of thermal origin, at temperatures of 0.3keV and 1keV.

(Hironori Matsumoto et al.) found that the hard component had a time variability of about 10^4 seconds a month. They found the luminosity of this hard component in the 0.5 to 10keV band ranges from 3x10^40 erg/s to 1x10^41 erg/s. Due to the spatial positioning of this component, it is hypothesised to be originating as a point source from the luminous X-ray source at the centre of NGC 3034. The remaining spectrum was found by subtracting the highest and lowest states, which reveals a strong absorption feature. (Matsumoto et al.) state that this suggests the variable source is embedded in the galactic centre of NGC 3034. All of this is evidence for a low luminosity active galactic nucleus hidden in NGC 3034.

[16] Figure 7a shows the HI column density versus distance from the midplane. The central +- 1kpc from the midplane exhibits significant HI absorption.

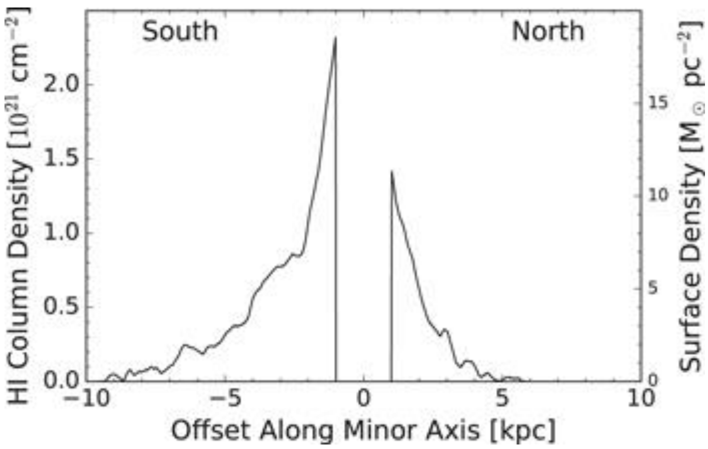


Figure 7a: HI column density versus offset from the minor axis.

This theory has proven very difficult to confirm due to the sheer volume of dust obscuring the view to the centre of the galaxy. [13] (K. A. Wills et al.) suggest that the 30 compact objects identified in the central regions of NGC 3034 are either young supernova remnants (SNRs) or radio supernovae. They acknowledge the contradiction of this theory of radio supernovae, being the lack of rapid variability of these sources, and the fact they can be resolved into shell-like structures. This implies many of these sources are likely to be SNRs.

Using VLA telescope images captured in 1995, they observed what they described as “an elongated continuum feature”. The image is shown in figure 7b. They measured the linear feature to be of length 45 pc, and of width 8pc. This feature can be confused with background emission, but can be interpreted as a one-sided radio ejection. This jet can be evidence of an AGN present- despite its orientation to be perpendicular to the disk. This alignment is not compulsory for radio jets from AGNs, as there has been evidence that such jets tend to avoid emerging along the minor axis of the galaxy. While this may be evidence for an AGN, it is again more likely to be that of SNRs, although one cannot conclude based on only radio spectral evidence.

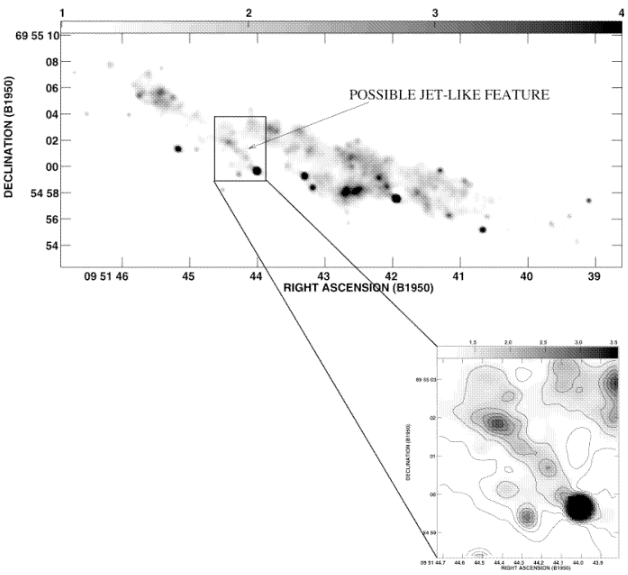


Figure 7b showing the linear feature which could be interpreted as a radio jet from sourced from an AGN.

## 8 SUPERNOVA SN 2014J

On the 21st of January 2014, Steve J. Fossey discovered a type 1a supernova, located at $09^h55^m42.15^s$ right ascension and $+69^d40^m25.8^s$ declination[22], by chance in a laboratory session at the University of London Observatory. Such supernovas are known as “standard candles” as they can be used as cosmic distance indicators (once the apparent magnitude and extinction have been determined).

Type 1a supernovae occur in a binary star system, whereby either one or both stars are white dwarfs. Since white dwarfs live at least one billion years, this supernova involved stars which originated before the starburst activity within NGC 3034. Characterised by a significant lack of hydrogen in their spectra, type 1a supernovae are caused when a white dwarf accretes a mass above the Chandrasekhar limit, which is 1.4Msun, from its companion star. The result is an exceptionally violent carbon fusion in the white dwarf core. [21]

[23] Figure 8a contains Chandra data of the supernova. Low-energy X-rays are red, medium; green and high; blue. The small boxes also show images of the region from before and after the explosion. The lack of X-rays suggests the site of the supernova is lacking in material, supporting the theory that a white dwarf had been collecting matter from a companion star. However, this mass transfer is not likely to have been completely efficient, and so bright X-rays would have been present. Therefore, it is speculated that the explosion was caused by the merging of two white dwarfs, and therefore little mass transfer.

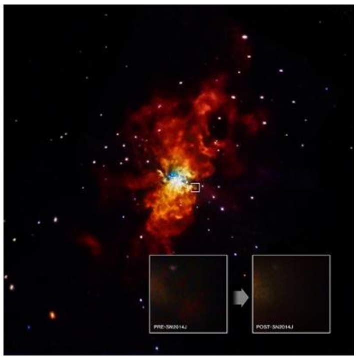

Figure 8a: Chandra Image of SN 2014J.

By producing a light curve using the Light Curve Generator by AAVSO [20], one can see that the time of peak brightness for SN 2014J was 02/02/2014. The curve is shown in figure 8b.

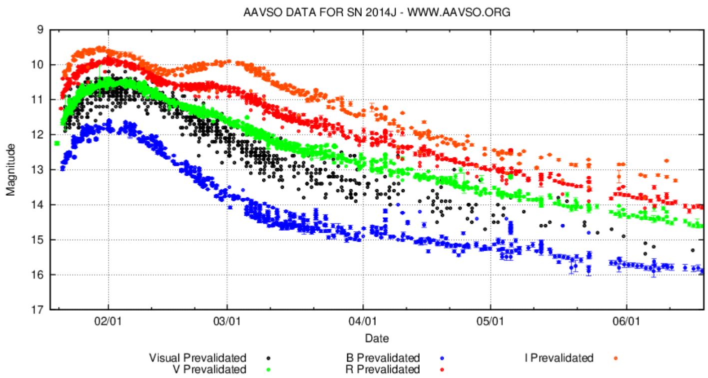


Figure 8b: Light Curve for supernova SN 2014J, plotted from 20th of January until the 20th of June 2014.

The maximum visible magnitude had an absolute value of roughly 10.5mag. The difference in the blue and visual magnitudes indicates the amount of interstellar reddening. The blue magnitude is approximately peaked at 11.8mag, leaving an extinction value (or local colour excess) of 1.3mag.

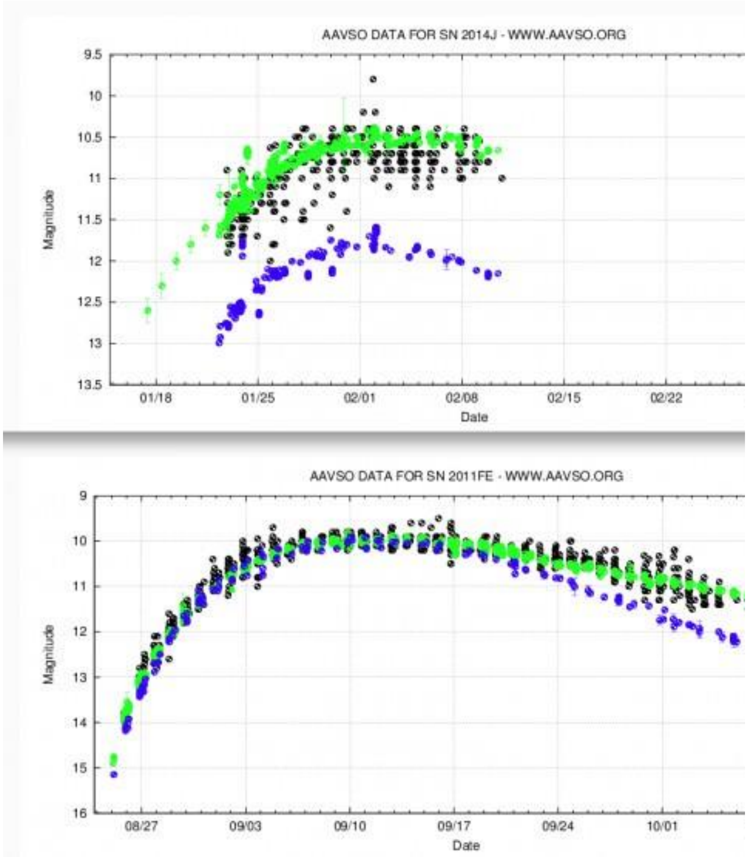


Figure 8c: Comparison of SN 2014J with SN 2011FE

Figure 8c compares SN 2024J with SN 2011FE, and the effects of extinction become more apparent here. However, once the effects of dust-attenuation have been acknowledged, one can accurately determine the distance to NGC 3034 using SN 2014J.

## 9 CONCLUSIONS

To summarise, NGC 3304 is an irregular dwarf starburst galaxy indicating some regular features such as a bar and spiral arms. It is located at right ascension $09^h55^m52.725^s$ and a declination value of $69^d40^m45.78^s$, with an average distance value of 3.835Mpc. Its high levels of dust obscurity along with the selectively unfavourable inclination angle of 77 degrees (causing NGC 3034 to appear almost edge-on) makes analysis of the distance and morphological components difficult, but allows for detailed access to the plumes of superwind visible along the minor axis. From the HI linewidth of the emissions, this dwarf galaxy can be approximately fitted within the scattered results of the Tully Fisher relation, resulting in an overestimated distance of around 5MPc. Using the TRGB, a more accurate and updated distance estimate was calculated to be 3.89Mpc. From kinematics of planetary nebula, the systematic velocity of NGC 3034 was found to be 200kms^-1, with a velocity dispersion of 60kms^-1. Moreover, the galaxy appears to be under no influence of internal dark matter, evident from the Keplerian decline of the rotation curve. The occurrence of SN 2014J has been the focus of many studies, proving a potential candidate for distance determination.

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