The Galactic Luminosity, Rotational Velocity, Nova and Supernova Rates

Optical observations of the Galaxy and the Tully–Fisher relation are both consistent with a Galactic luminosity $L_B = (2.3 \pm 0.6) \times 10^{10} L_B(\odot)$. With $h = H/100$ km s^{-1} Mpc^{-1}, the corresponding supernova rates are 0.7 h^2, 0.9 h^2 and 2.5 h^2 per century for supernovae of types Ia, Ib and II, respectively. The ratio of the number of novae to the number of SNIa is estimated to be 4100 ± 2700. From a comparison of the luminosities of M31 and the Galaxy, the Galactic nova rate is <13 per year indicating that >20% of all Galactic novae are presently being discovered.

Key Words: *galaxy luminosity*, *nova rates*, *supernova rates*

1. THE LUMINOSITY OF THE GALAXY

The Galactic supernova rate may be derived from observations of the extra-Galactic supernova frequency once the Hubble parameter, and both the absolute magnitude and the Hubble type of the Galaxy are known. At present there is a fairly broad consensus, cf. van den Bergh,[1] that the Galaxy has a Hubble type *between* Sb and Sc. Because we live inside the Milky Way System, the absolute magnitude of the Galaxy is difficult to determine. Recent estimates for the Galactic luminosity range from $1.6 \times 10^{10} L_B(\odot)$ $[M_B = -20.0]$ (de Vaucouleurs and Pence[2]) to $3.9 \times 10^{10} L_B(\odot)$ $[M_B = -21.0]$ (Tammann 1981[3]). From a recent review of presently available optical data, de Vaucouleurs[4] derives a face-on absolute magnitude $M_B^0 = -20.2 \pm 0.15$ for the Galaxy. An

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additional correction of $A_B \approx 0.3$ mag has to be applied to this value to transform it to the dust-free magnitude $M^{0,i}_{BT}$ of Sandage and Tammann.[5] [According to Sandage and Tammann, values of A_B for pole-on galaxies range from 0.43 mag for Hubble types Sc-Sb to 0.28 mag for types Sbc-Sd.] The value $M^{0,i}_{BT} = -20.5 \pm 0.2$ corresponds to a blue luminosity of $(2.5 \pm 0.5) \times 10^{10}$ $L_B(\odot)$. This result in consistent with the work of van der Kruit,[6] who used photometry obtained with the Pioneer 10 spacecraft to obtain a total luminosity of $(1.8 \pm 0.3) \times 10^{10}$ $L_B(\odot)$ for the Galactic disk. To this value should be added a spheroid luminosity of $(1.5 \pm 0.5) \times 10^9$ $L_B(\odot)$ for a total Galactic blue luminosity of $(1.95 \pm 0.3) \times 10^{10}$ $L_B(\odot)$. This value is consistent with, although somewhat lower than, the value obtained by de Vaucouleurs.[4] It should, perhaps, be emphasized that both of the determinations given above are based on the assumption that the Sun is located at a distance $R_0 = 8.5$ kpc from the Galactic center. For other assumed Galactocentric distances, the Galactic disk luminosity scales as $(R_0/8.5)^2$.

The Tully–Fisher[7] relationship between the velocity widths of 21 cm line profiles and the luminosities of spiral galaxies may also be used to estimate the luminosity of the Galaxy. In his recent review paper, de Vaucouleurs[4] finds a circular velocity near the sun $V_0 = 220 \pm 15$ km s^{-1}. Brand *et al.*[8] obtain $V(\max) - V_0 \approx 10$ km s^{-1}, so that the half-width of the line observed from outside would be $V(\max) \approx 230 \pm 15$ km s^{-1}. A line width of 460 ± 30 km s^{-1} will therefore be adopted for the Milky Way system.

A Tully–Fisher relation that is not affected by Malmquist bias may be derived from the Huchtmeier and Richter[9] catalog of HI observations for all spiral and irregular galaxies with redshift (corrected for Local Group motion) $\leqslant 500$ km s^{-1} in the catalog of Kraan–Korteweg and Tammann.[10] Adopting the $\Delta V(\max)$ observations of Huchtmeier and Richter,[9] the $M^{0,i}_{BT}$ values of Sandage and Tammann,[5] and excluding galaxies with $i \geqslant 80°$ (for which internal absorption corrections are large and uncertain) as well as NGC 5229 (which is the faintest object in the sample), the Sb, Sbc and Sc galaxies observed by Huchtmeier and Richter give a Tully–Fisher relation that yields $M^{0,i}_{BT} = -20.73 \pm 0.42$ or $L_B = (3.0 \pm 1.2) \times 10^{10}$ $L_B(\odot)$ for $\Delta V(\max) = 460 \pm 30$ km s^{-1}. If the Local Group, South Pole Group and M81 Group distances used by Sandage and Tammann (1981) are left unaltered, but the distances of all other galaxies are computed using H = 75 km s^{-1} Mpc^{-1}, rather than H = 50 km s^{-1} Mpc^{-1}, then $M_{BT}^{0,i}$ = -20.12 ± 0.57 or L_B = $(1.7 \pm 1.0) \times 10^{10}$ $L_B(\odot)$ is obtained for the Galaxy. In summary it is concluded that all of the currently available data are consistent with a Galactic luminosity L_B = $(2.3 \pm 0.6) \times 10^{10}$ $L_B(\odot)$.

2. THE GALACTIC SUPERNOVA RATE

In a recent paper van den Bergh, McClure and Evans[11] derive supernova frequencies of 0.3 h^2, 0.4 h^2 and 1.1 h^2 per 10^{10} $L_B(\odot)$ per century for supernovae of types Ia, Ib and II, respectively, in an "average" Shapley–Ames galaxy. Combining these rates with the value L_B = 2.3×10^{10} $L_B(\odot)$ for the Galaxy yields Galactic supernovae rates of 0.7 h^2, 0.9 h^2 and 2.5 h^2 per century for types Ia, Ib and II, respectively. Note that these values have a statistical uncertainty of about a factor of 2. Furthermore these estimates depend on the assumption that the stellar population mix in the Galaxy is similar to that of an "average" Shapley–Ames galaxy.

From the supernova rates quoted above, one obtains a total Galactic supernova rate of ~4 h^2 per century. This value may be compared to Tammann's[3] estimated rate of 16 h^2 supernovae per century. (The latter value would, however, decrease to 9 h^2 supernovae per century if Tammann had also used a Galactic luminosity of 2.3×10^{10} $L_B(\odot)$, rather than 3.9×10^{10} $L_B(\odot)$.)

3. THE GALACTIC NOVA RATE

Both novae and supernovae of Type Ia are presently believed to occur in white dwarf stars that are members of close binary systems associated with an old stellar population. It is therefore, perhaps, reasonable to assume that novae and SNIa have similar galactic distributions and that the ratio of the number of novae to the number of SNIa is approximately constant within such old populations. In the remainder of this section, some of the consequences of this hypothesis will be explored. The strategy is (a) to determine the ratio of novae to SNIa from elliptical galaxies, (b) to normalize to M31 where the nova rate is relatively well known, and then (c) to predict the Milky Way nova rate from the ratio of its luminosity to that of M31.

During an observing run lasting ≈0.05 years, Pritchet and van den Bergh[12] observed 8 novae at maximum light in 4 fields in Virgo giant elliptical galaxies. The integrated luminosity of these fields is $B = 9.52$. From a comparison of the light curves of novae in M31 with those in the Virgo cluster, van den Bergh[13] finds a Virgo distance modulus $(m-M)_0 = (m-M)_B = 31.35 \pm 0.41$. It follows that the nova rate in Virgo ellipticals is 160 ± 57 per year in a population with $M_B = -21.83 \pm 0.41$. Adopting $M_B(\odot) = +5.48$ this yields a rate of 19 ± 10 novae per year per 10^{10} $L_B(\odot)$. According to Tammann[3] the *super*nova rate in E galaxies is $(0.88 \pm 0.24)h^2$ per 10^{12} $L_B(\odot)$ per year. Adoption of van den Bergh's[13] value $h = 0.72 \pm 0.14$ yields a supernova rate of 0.46 ± 0.18 supernovae per 10^{12} $L_B(\odot)$. [Van den Bergh, McClure and Evans[11] find a supernova rate which is ~3 times smaller than that obtained by Tammann.[3] However, this lower rate refers mainly to spiral galaxies. The statistics of Evans' data base are not yet good enough to show if a similar correction also applies to elliptical galaxies.] From the figures given above, the ratio of the number of novae to the number of SNIa (which are the only type of supernova believed to occur in elliptical galaxies) is 4100 ± 2700. This number is independent of the adopted value of the Hubble parameter because both the nova and the supernova frequencies scale as h^2.

Following Sandage and Tammann[5] the values $B_T = 4.38$, $A_i = 1.03$ and an apparent distance modulus $(m-M)_B = 24.55$ (van den Bergh[13]) will be adopted for M31 which yields $M_{BT}^{0,i} = -21.2$, corresponding to 4.7×10^{10} $L_B(\odot)$, for the Andromeda nebula. In Section 1 a value $L_B = 2.3 \times 10^{10}$ $L_B(\odot)$ was obtained for our own Galaxy, so that M31 is ~2 times as luminous as the Galaxy in blue light. Because the Andromeda nebula has an earlier Hubble type than the Galaxy, the old stellar population in M31 should be more than twice as numerous as that in our Milky Way system. Since novae are predominantly members of such an old population, it appears reasonable to assume that the nova rate in M31 is also more than twice as great as that in the Galaxy. According to Arp[14] the M31 nova rate is 26 ± 4 per year. If this estimate is correct then the Galactic nova rate is <13 per year. This value conflicts, at the 2.5σ level, with the Galactic nova rate of 73 ± 24 that Liller and Mayer[15] obtain by applying large corrections to the actually observed Galactic nova rate.

Excluding recurrent novae, X-ray novae, and objects which the IAU Circulars called "novae" but which are probably distant supernovae, there are 25 Galactic novae that were discovered during the 10-year period 1977–1987. This yields an average rate of nova discoveries of 2.5 per year. If our previous estimate of the Galactic nova rate is correct this indicates that >20% of all Galactic novae are presently being discovered.

4. NOVA AND SUPERNOVA RATES

From Arp's[14] nova rate of 26 ± 4 per year in M31, together with the nova/supernova ratio determined above, one would expect a rate of 0.6 ± 0.4 supernovae of type Ia per century in M31. This estimate is consistent with the observation that only one supernova (S Andromedae), which was of indeterminate type, has occurred in the Andromeda nebula during the last century.

A total of 21 Galactic novae with $V(\max) < 10.0$ have been found during the last 10 years, yielding a frequency of ~210 per century for such objects. Assuming that SNIa and novae have the same Galactic distribution, and adopting $M(\max) = -8$ for novae and $M(\max) = -19$ for supernovae of type Ia, yields a predicted Galactic rate for SNIa with $V < -1$ of ~210/4100 ≈ 0.05 per century, i.e., about one per 2000 years. In fact three objects (Lupus 1006, Tycho 1572 and Kepler 1604), which on the basis of their location far from the Galactic plane, light curve and/or environment are believed to have been supernovae of Type Ia, are known to have occurred during the last millenium. Perhaps we have been exceedingly lucky. Alternatively our estimated SNIa rate may be too low. The difference between the observed and expected SNIa rate would be reduced if Kepler's supernova was actually produced by a runaway disk star, as has recently been proposed by Bandiera.[16] From Poisson statistics the probability of observing 2 or more

SNIa per millenium (if the average rate is 0.5 per millenium) is 9%.

SIDNEY VAN DEN BERGH
Dominion Astrophysical Observatory,
5071 W. Saanich Road,
Victoria, British Columbia,
V8X 4M6, Canada

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