RESEARCH

Amount of stars and location (turned out to be harder than we thought): Approximately 100-400 billion stars in the Milky Way (most common figure seems to be 200 billion). The galaxy is spiral and 120,000 light-years wide (radius 60,000) - we're halfway out at 27,000.

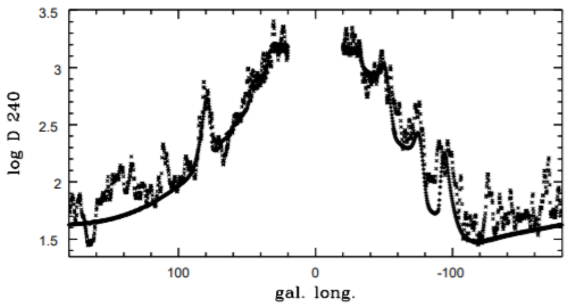


FIG. 5.—240 μm emission profile for the data (*crosses*) and model (*diamonds*) within 0°.17 of the GP ($b = 0$), on a logarithmic scale (log D).

The mass of the bulge (long bar) of the galaxy is around (1.69 ± 0.12)e10 solar masses ($M_\odot$), while the mass of the stellar disk is (2.32 ± 0.24)e11 $M_\odot$ - (5.78 / 6.79 / 8.01)% of the milky way's mass is in the bulge. The bulge's radius is 6500 lya (10.83% the full radius) - 1.17% of the area (if we take the galaxy to be 2D).

$$\Sigma_{\rm D}(R) = \frac{1}{\pi^2 G}\times \left[\frac{1}{R}\int_0^R \left(\frac{dV^2}{dr}\right)_x K\left(\frac{x}{R}\right) dx + \int_R^\infty \left(\frac{dV^2}{dr}\right)_x K\left(\frac{R}{x}\right)\frac{dx}{x}\right].$$

$$\Sigma_b(r) = \Sigma_{b0} exp\left[-(r/r_0)^{1/4}\right], \quad (1)$$

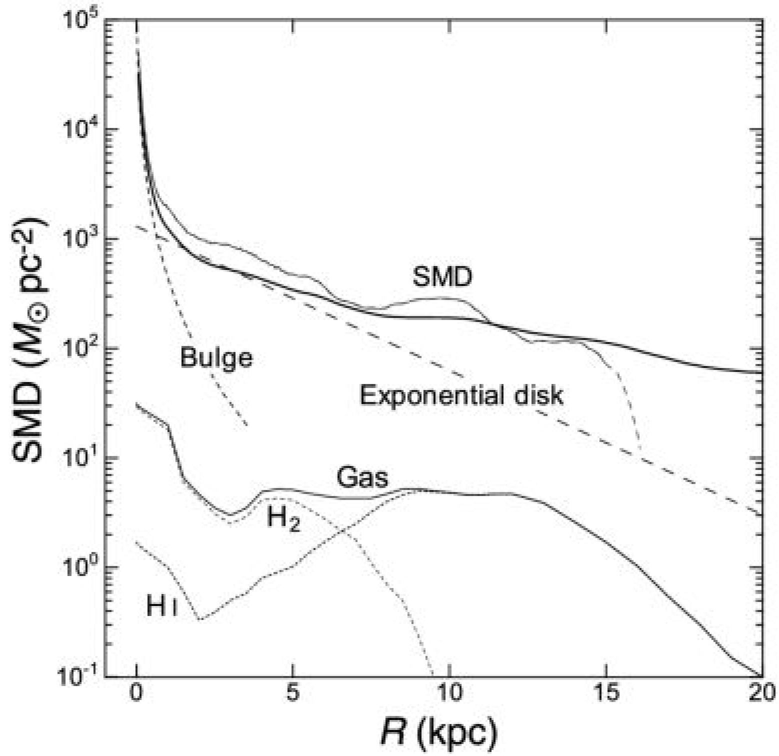
where , Σ_{b0} is the central surface mass density of the bulge, r is the Galactic radius, r_0 is the characteristic radius of the bulge and is determined by the effective radius r_e at which the mass density of the bulge drops to half of its maximum. r_0 and r_e satisfy a relation given by $r_e = b^n r_0$, where b is a solution of equation $\gamma(b,8) = \Gamma(8)/2$ with γ and Γ are respectively

taken from ref.7). It has been found that taking $r_e = 0.75\ kpc$ and $\Sigma_{b0} = 5.12 \pm 0.37 \times 10^6 M_\odot/pc^2$ gives a best curve fit to the observed rotation velocities from the Galactic centre

$$\Sigma_s(\mathrm{r}) = \frac{\Sigma_{s0} l_c}{\sqrt{(r-r_b)^2 + l_c^2}} \quad , \quad (3)$$

where, Σ_{s0} is the maximum surface mass density of the stellar disk, r_b is the radius of the central bulge, and l_c is a characteristic length of the stellar disk.

rb = 2.0kpc; lc = 2.5kp; sO = (611 ± 44)$M_\odot$/(pc^2)



This shows the Surface Mass Density in disk galaxies with the bulge's influence extending to roughly 10% of the galaxy, making this analogous to the Milky Way. The gradient of the exponential disk line is -56.38 while the gradient of the mass distribution between R = 2 and R = 20 is -53.67

Average rate of star formation in galaxy:
About 4 solar masses per year (approx 7 stars)
Around 3.5% of the stars in the bulge are younger than 5 billion years old (roughly the age of the sun)

The fraction of stars which are Sun-like
63/800 = 7.875%
1.575e10 sun-like stars

The fraction of those stars that have planets:
Should be at least as many planets as stars - (100 to 400 billion planets)
26 ± 3% of sun-like stars have Earth-sized planets (1-2 R)

The average number of planets that can potentially support life per star that has planets:
11 ± 4% of Sun-like stars have Earth-sized planets (1-2 R) which receive Earth-like energy (1-4 F) (between 24.14% to 42.31% to 65.21%)

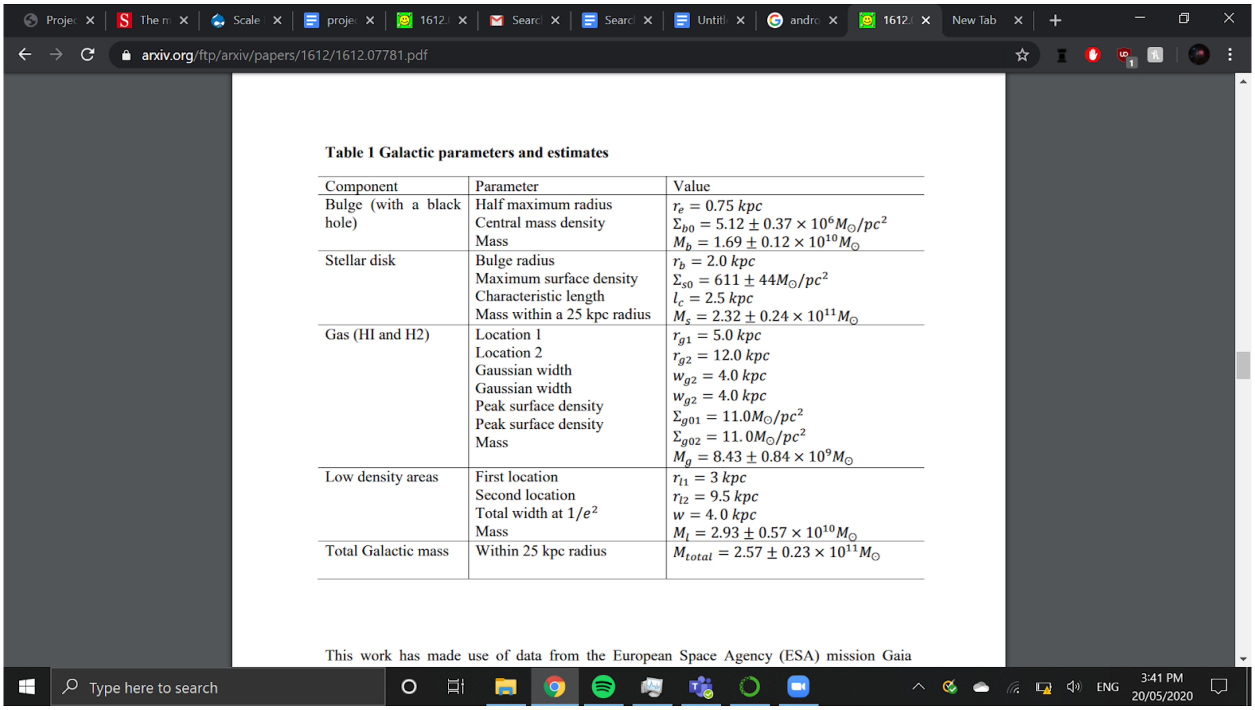


Table 1 Galactic parameters and estimates

Component	Parameter	Value
Bulge (with a black hole)	Half maximum radius Central mass density Mass	$r_e = 0.75\ kpc$ $\Sigma_{b0} = 5.12 \pm 0.37 \times 10^6 M_\odot/pc^2$ $M_b = 1.69 \pm 0.12 \times 10^{10} M_\odot$
Stellar disk	Bulge radius Maximum surface density Characteristic length Mass within a 25 kpc radius	$r_b = 2.0\ kpc$ $\Sigma_{s0} = 611 \pm 44 M_\odot/pc^2$ $l_c = 2.5\ kpc$ $M_s = 2.32 \pm 0.24 \times 10^{11} M_\odot$
Gas (HI and H2)	Location 1 Location 2 Gaussian width Gaussian width Peak surface density Peak surface density Mass	$r_{g1} = 5.0\ kpc$ $r_{g2} = 12.0\ kpc$ $w_{g2} = 4.0\ kpc$ $w_{g2} = 4.0\ kpc$ $\Sigma_{g01} = 11.0 M_\odot/pc^2$ $\Sigma_{g02} = 11.0 M_\odot/pc^2$ $M_g = 8.43 \pm 0.84 \times 10^9 M_\odot$
Low density areas	First location Second location Total width at $1/e^2$ Mass	$r_{l1} = 3\ kpc$ $r_{l2} = 9.5\ kpc$ $w = 4.0\ kpc$ $M_l = 2.93 \pm 0.57 \times 10^{10} M_\odot$
Total Galactic mass	Within 25 kpc radius	$M_{total} = 2.57 \pm 0.23 \times 10^{11} M_\odot$

This work has made use of data from the European Space Agency (ESA) mission Gaia

The fraction of planets that could support life that actually develop life at some point:
Can count some stars out - too big it dies too quick for life
Apart from that we can only estimate

The fraction of planets with life that actually go on to develop intelligent life:
Estimate

The average number of supernovae and the locations of them:
Approx 1 every 50 years in Milky Way

We can therefore take the surface density of SNe in spiral galaxies to follow

$$\sigma(r) = \sigma_c \exp(-r/R_{scl}), \quad (1)$$

with r the radial distance in the plane of the galaxy from its centre, σ_c the surface density at the centre of the galaxy, and R_{scl} the exponential scalelength. This surface density function is a number

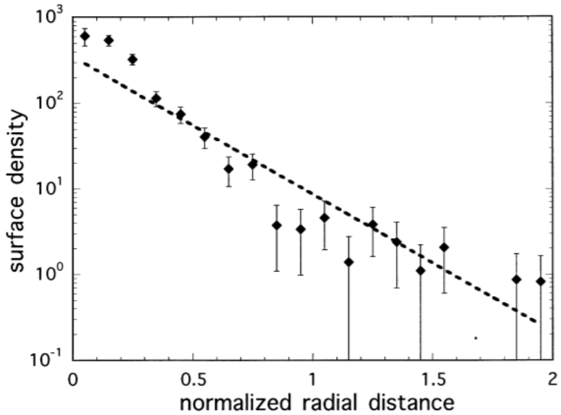


Figure 1. The surface density of SNe in external spiral galaxies as a function of normalized radial distance from the host galaxy centre. The curve fitted has the equation $\sigma(r) = 350\exp(-r/0.27)$ and gives a correlation coefficient of 0.98.

Assuming the SN surface density distribution to be rotationally symmetric about the centre of the Milky Way Galaxy at $r = 0$, the number of SNe occurring within a given area A of the Galactic disc, in some time interval, is given by

$$n_A = \iint_A \sigma(r)\, r\, dr\, d\theta, \tag{2}$$

with r and θ the plane polar cooordinates in the disc. To calibrate the historical SN rate within the Milky Way, this integral has to be evaluated for the whole Galaxy, yielding n_{Gal}, and from the Sun out to the horizon of the historical SNe, yielding n_{loc}, the number of SNe visible locally during the same time interval.

For the 'whole Galaxy' integral, substituting the exponential form (1) into (2) and integrating out to the cut-off radius R_{cut} of the Galactic disc, beyond which the SN distribution is negligible, yields

$$n_{\mathrm{Gal}}/\sigma_{\mathrm{c}} = 2\pi R_{\mathrm{scl}}^2[1 - (1 + R_{\mathrm{cut}}/R_{\mathrm{scl}})\exp(-R_{\mathrm{cut}}/R_{\mathrm{scl}})]. \tag{3}$$

For $R_{\mathrm{cut}}/R_{\mathrm{scl}} > 5$, the approximation

$$n_{\mathrm{Gal}}/\sigma_{\mathrm{c}} \approx 2\pi R_{\mathrm{scl}}^2 \tag{4}$$

holds, with an error of 4 per cent or less: R_{cut} becomes effectively infinite.

The 'local' integral may be evaluated numerically, integrating from the Sun out to the horizon radius R_{hor} for the historical SNe, or approximately by replacing the surface density function in the vicinity of the Solar system by the constant $\sigma_{\mathrm{c}}\exp(-D_{\odot}/R_{\mathrm{scl}})$, the value of $\sigma(r)$ at our distance $D_{\odot}$ from the Galactic Centre, yielding

$$n_{\mathrm{loc}}/\sigma_{\mathrm{c}} \approx \pi R_{\mathrm{hor}}^2 \exp(-D_{\odot}/R_{\mathrm{scl}}). \tag{5}$$

The approximate results (4) and (5) give the simple formula

$$n_{\mathrm{Gal}}/n_{\mathrm{loc}} \approx 2(R_{\mathrm{scl}}/R_{\mathrm{hor}})^2 \exp(+D_{\odot}/R_{\mathrm{scl}}) \tag{6}$$

for the ratio of SN numbers Galaxy-wide and seen locally, in a given time interval.

In this way, the Galactic SN frequency may be calculated from

$$\nu = (n_{\mathrm{Gal}}/n_{\mathrm{loc}})N_{\mathrm{SN}}/10 \text{ SNe century}^{-1}, \tag{7}$$

where N_{SN} is the number of local SNe (within the horizon) in a millennium.

The average amount of metallicity:

for the solar spectrum). We have used a MARCS75 model (Gustafsson et al. 1975), the MARCS2002 model (Gustafsson et al. 2002), an ATLAS9 model, the Holweger (1974) semi-empirical model, and finally, the Grevesse & Sauval (1999) revised semiempirical model to derive the solar oxygen content. We find $\log \varepsilon_O$ to be 8.74, 8.81, 8.84, 8.88, and 8.84, respectively, for these models. As can be seen, these values are more akin to the older solar value of $\log \varepsilon_O = 8.92$, which if used would yield a Cepheid/supergiant [O/H] ratio of -0.18, as previously found. In our abundance tables we give [O/H] computed using a solar oxygen abundance of 8.69 but do not assign any specific importance to the chosen zero point. It appears that the oxygen abundance problem in intermediate-mass stars persists.

4.2. *Spatial Abundance Distributions*

4.2.1. [Fe/H] *Distribution*

Based on Tables 2–5, and the results of Papers I–V, KWA05, and Yong et al. (2006), we have constructed radial (1D) distributions of elemental abundances. From the Yong et al. data we use the 15 stars in that study that are not included in our studies. We have placed their [Fe/H] data on our scale using the transformation given in § 4.1.2 and shown in Figure 2. Distances for the Yong et al. stars have been derived using the formalism of § 3.3. The galactocentric distances are comparable to those of Yong et al. with the glaring exception of HQ Car, for which the derived distance from the $\langle V \rangle$ and M_V data is 12.4 kpc, while the ($\langle K \rangle$, M_K) data used by Yong et al. yield 15.7 kpc. In Figure 10 we show the gradient data for iron.

If we divide the whole range into three parts (zone I: 4.0–6.6 kpc; zone II: 6.6–10.6 kpc; and zone III: 10.6–14.6 kpc), then the statistics for each zone and the total sample for iron (the most reliable abundance) are as follows: for zone I,

$$[\mathrm{Fe/H}] = -0.128(\pm 0.050)R_G + 0.936(\pm 0.293),$$
$$\langle[\mathrm{Fe/H}]\rangle = +0.182 \quad (\mathrm{s.d.} = 0.128, \quad n = 13),$$

for zone II,

$$[\mathrm{Fe/H}] = -0.026(\pm 0.007)R_G + 0.236(\pm 0.061),$$
$$\langle[\mathrm{Fe/H}]\rangle = +0.015 \quad (\mathrm{s.d.} = 0.093, \quad n = 141),$$

for zone III,

$$[\mathrm{Fe/H}] = -0.090(\pm 0.013)R_G + 0.849(\pm 0.173),$$
$$\langle[\mathrm{Fe/H}]\rangle = -0.297 \quad (\mathrm{s.d.} = 0.200, \quad n = 51),$$

and for the total,

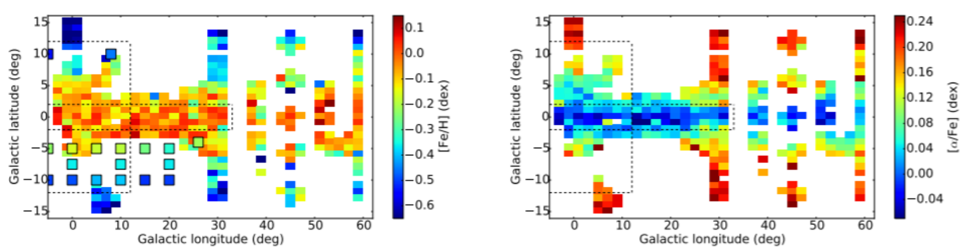
$$[\mathrm{Fe/H}] = -0.068(\pm 0.003)R_G + 0.585(\pm 0.033).$$

As one can see, the mean metallicities for these zones are different. The mean metallicity of zone II is heavily influenced by the group of higher abundance stars at galactocentric radius $R_G \sim 9$–10 kpc, while in zone III the low-abundance stars at about 14 kpc have a similar influence. Without those stars the slope would be essentially constant across zones II and III. The difference in the slopes and mean metallicities across the disk are traced in the plots for all elements through the iron peak.

The linear gradient that we have derived here is $d[\mathrm{Fe/H}]/dR_G = -0.068$ dex kpc^{-1} for the total sample. If one uses our data exclusively, one obtains a gradient of -0.059 dex kpc^{-1}. The addition of the lower abundance stars of Yong et al. (2006) has a significant influence on the gradient value. There have been many attempts to determine the value of the gradient (see Paper I for a brief history). The value derived here is somewhat higher than the recent value from Maciel et al. (2005) of $d[\mathrm{Fe/H}]/dR_G = -0.054$ dex kpc^{-1} (based on our previous Cepheid abundances and a somewhat revised distance scale). L. Chen & J. L. Hou[5] derived $d[\mathrm{Fe/H}]/dR_G = -0.063$ dex kpc^{-1} from a sample of young open clusters. These values are also in accord with the somewhat older results of Friel (1999) and Phelps (2000), who obtained $d[\mathrm{Fe/H}]/dR_G = -0.06$ dex kpc^{-1}.

In previous papers we have smoothed the [Fe/H]-R_G relation by use of a local smoothing method (LOWESS, in particular). Figure 10 includes the result of such a smoothing. As can be seen, the smoothed fit is not significantly different from the linear fit, especially at galactocentric distances greater than about 7 kpc. Interior to that radius there is an increase in the slope, but that region is sampled only by 13 stars (relative to the 205 in the

[5] See http://www.rssd.esa.int/index.php?project=Gaia&page=Gaia_2004_Proceedings.



(a) [Fe/H] map

(b) [α/Fe] map

Figure 2. (a) [Fe/H] and (b) [α/Fe] maps for the 8500 bulge and disk stars from APOGEE and 8000 ARGOS bulge stars (in the larger outlined boxes for the [Fe/H] map only) spanning heliocentric distances of 4–12 kpc. The dashed line indicates approximate outline of the 180 pc thin bar identified by Wegg *et al.* (2015) and the larger box represents the approximate outline of the boxy bulge in the COBE image (Dwek *et al.* 1995).

Lots of iron in middle of galaxy, lots of alphas in the edges

The GHZ of the Milky Way is an annulus 7-9 kiloparsec (7-9 *3e3 lya) from the Milky Way centre.

With too little metallicity, Earth-like planets will not form, with too much metallicity, giant planets will destroy Earth-like planets

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