

## D-3 ABUNDANCE GRADIENT IN INTERSTELLAR MEDIUM

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### ABSTRACT

I discuss in this review the implications of observed abundance gradient in the interstellar medium on the chemical evolution of the Galaxy. I describe the ingredients that are required to develop enrichment models and also the predictions of different models on the variation of metallicity in the galactic disk. The observed abundance gradient derived by various workers using different kinds of objects are also summarized. A few other observations that are relevant to the problem of chemical evolution - like the G dwarf problem and the abundance ratios of the elements formed by primary and secondary processes of nucleosynthesis - are also briefly discussed. Some of the advanced models of chemical evolution that are able to account for all these observations are described. It is necessary to extend the metallicity surveys to the outermost parts of the galactic disk since there is evidence that the chemical evolution of these parts has been radically different from that of the solar neighbourhood. The additional constraint imposed by such observations would lead to a more comprehensive theory of the chemical evolution of the galactic disk.

### 1. INTRODUCTION :

In this review I will discuss the implications of the observed abundance gradients in the Galaxy in terms of its chemical evolution. It has been observed in a large number of normal spirals (including our own) and also in giant elliptical galaxies that metallicity in the inner regions is higher than in the outer parts. Abundance gradient is the measure of variation of the chemical composition across the galactic disk. In spirals, the ones with later morphological types, e.g. NGC 300 and M 33 display steeper abundance gradients ( $\sim 0.10$  dex  $\text{kpc}^{-1}$ ) compared to earlier types like M 51 and M 31 ( $\sim 0.04$  dex  $\text{kpc}^{-1}$ ). Among irregulars, a very small and poorly determined abundance gradient exists for Large Magellanic Cloud (LMC) and no abundance gradient for Small Magellanic Cloud (SMC).

Abundance gradients have been observed in our Galaxy as well as in external galaxies from the observations of HII regions. These studies yield directly the present chemical composition of the interstellar medium (ISM). By the study of emission-line ratios in the optical spectra of HII regions, one can derive the relative abundances He/H, N/H, O/H and N/S. The high intrinsic brightness of these objects makes them very suitable for gradient determinations. However, the emission spectra of HII regions contain the lines of only the light elements. One needs to observe the atmospheres of stars in order to derive the gradient in heavy elements.

It should be borne in mind that if stellar abundances are to be used for determining the abundance gradient, then the abundance of the element considered should be representative of the interstellar gas out of which the stars is formed. For example, the atmospheric abundance should not be affected by mixing with the interior of the star where nuclear reactions take place. Also, the atmospheric abundance would represent the interstellar abundance as it was when the star was formed. One can probe the past abundance gradients using a sample of stars of homogenous ages. Furthermore, one also needs to know the accurate birthplaces of these stars. For fairly young objects, a sufficiently precise knowledge of the velocity, position and age permits a direct estimation of the birthsite. For the stars that are members of clusters, the cluster ages can be determined from the turn-off point of the main sequence in the cluster HR diagram. For objects like Cepheids for which the period-age relationship is established the age can be estimated from the period. For old stars ( $\text{age} > 4 \times 10^8 \text{yr}$ ) having a galactic orbit between  $\omega_a$  and  $\omega_p$  (apogalactic and perigalactic radii), it is generally assumed that the birthplaces can be statistically approximated by the mean orbit  $\omega = 0.5 (\omega_a + \omega_p)$ . With such a hypothesis one can obtain the evolution of the radial abundance gradient with time, dividing the sample stars into different age groups on the basis of the eccentricity of their galactic orbits (Mayor 1976).

## 2. THE MODELS OF GALACTIC EVOLUTION

The basic postulates of the models of galactic evolution are the following :

(i) Galaxies are formed by the collapse of intergalactic gas accompanied by star formation either on a short timescale to make elliptical galaxies, and the bulge and halo components of spirals or on a long timescale to make disk components of spirals and irregulars.

(ii) The primordial gas that contains H, He and Li is enriched in heavier elements by the material ejected by massive stars in the later stages of their evolution.

### 2.1 *Ingredients for the construction of galactic evolution model*

(i) The models of the end product of stellar evolution :

To develop an enrichment model, a good understanding of nucleosynthesis and evolution timescale for stars of different mass is necessary. The stars of about one solar mass or less have evolutionary times so long that they do not return significant gas to the ISM. They simply lock up a part of ISM and take it out of circulation. The stars of intermediate mass ( $1 M_{\odot}$  to  $\sim 10 M_{\odot}$ ) eject the excess of material above the white dwarf residue as gas that may have undergone some secondary processing but no primary processing; they therefore do not enrich the ISM in oxygen and metals but

only in carbon, nitrogen and the s-process elements. The more massive stars ( $M \gtrsim 10 \odot$ ) evolve fast and eject the products of primary nucleosynthesis that can be built up directly from hydrogen and helium - e. g. C, O and most of the species up to iron group. Secondary elements like N and the s-process elements also would be synthesized in the next generation stars that are born with C, O models that serve as seed nuclei, by the process of fast and slow neutron capture.

(ii) Initial mass function :

Now to march from the evolution of single stars to the enrichment of ISM resulting from a population of stars we require the relative birthrates of the stars with different masses. The initial mass function (IMF), which describes this was first introduced by Salpeter (1955) who deduced it from the star counts as a function of magnitude or spectral type using the mass-luminosity relation.

(iii) The rate of star formation :

Star formation in the galaxies with disks is a sporadic phenomenon and the physical processes associated with it are not clearly understood. However, if the average effect of star formation over the large regions and timescales - is to be studied, then it is considered adequate to adopt a power-law dependence of the star-formation rate (SFR) on volume density or surface density. In addition to the above ingredients, the assumptions about the environments in which star formation and stellar evolution take place are also important and we shall discuss them later.

## 2.2 Simple model of galactic evolution

Talbot and Arnett (1973) have combined the IMF and models of end product of stellar evolution to form a simplified model which is very useful in a study of the galactic chemical evolution. Let us define the two important parameters relevant to the enrichment problem. The first of these is the mass fraction  $\beta$  in each generation that is being returned to ISM. Second, the yield ( $\rho$ ) of primary element defined as the ratio of the rate at which the element Z is produced by the event of nucleosynthesis and ejected into ISM to the net rate at which the gas is being removed from ISM by star formation. If we use the instantaneous recycling approximation where one assumes the evolutionary processes to take place on much shorter timescales compared to the timescale of galactic evolution, these quantities are constant, characteristic of the IMF adopted. The abundance of heavy element in the gas can be deduced as

$$Z = \rho \ln (1 + s/g)$$

where s is the mass locked up in stars including compact remnants and g the mass of gas that is left including the processed gas. If we take a simple model of galactic evolution where the star formation is assumed to take place according to an invariable IMF in an isolated and well-mixed zone,

which initially consisted of pure gas with no heavy elements, then for this isolated zone the yield  $p$  will be constant. Searle and Sargent (1972) pointed out that the above equation predicts a large-scale abundance gradient in the galactic disk, provided that one assumes evolution to take place separately in concentric zones, because  $s/g$  generally decreases as we go outwards from the central regions. One could estimate this effect quantitatively. By the surface photometry of a large number of spiral galaxies, Freeman (1970) reported that the surface density  $s+g$  (which is projected volume density of the gas and stars on the galactic disk) decreases outwards exponentially as

$$s+g = \frac{\alpha^2 M}{2\pi} e^{-\alpha R}$$

where  $M$  is the total mass of the disk,  $R$  is the radial distance from the centre and  $\alpha$  is a constant. Now one can write

$$Z = \text{constant} - \rho \propto R$$

where  $\text{constant} = \rho \ln \frac{\alpha^2 M}{2\pi g}$ . Therefore the abundance  $Z$  is predicted to decrease linearly with the radial distance.

### 3. SUMMARY OF THE ESTIMATES OF THE ABUNDANCE GRADIENT

#### 3.1 Observations of HII regions and planetary nebulae

Abundance gradient in our Galaxy has been derived from the observations of HII regions by a number of investigators. Sivan (1976) derived

an abundance gradient for  $N/S$  based on the line intensity ratio  $[NII] \lambda\lambda [6548, 6584] / [SII] \lambda\lambda [6717, 6731]$  from a study of ten large low-density HII regions distributed over a galactocentric distance range of 5-6 kpc — (7.95 kpc — 13.48 kpc). The above line-intensity ratio is known to be proportional to  $N/S$  abundance ratio in low-density ( $n_e < 1000 \text{ cm}^{-3}$ ) HII regions. Peimbert et al, (1978) derived abundance gradients in  $O/H$ ,  $N/H$ ,

$N/S$  and  $He/H$  by photoelectric spectrophotometry of emission lines in the region  $3700 \text{ \AA} - 7400 \text{ \AA}$  for five HII regions covering a galactocentric distance range from 8.4 - 13.9 kpc. In a similar investigation but covering larger spectral region and using 15 HII regions, Hawley (1978) derived shallower gradients for  $O/H$  and  $N/H$  and no gradient for  $He/H$ . Talent and

Dufour (1978) derived  $O/H$ ,  $N/H$ ,  $N/S$  and  $He/H$  abundance ratios for four HII regions in the Perseus arm and by combining this data with the other HII regions derived gradients, which are in fair agreement with earlier estimates. Also, Talent and Dufour found that the variation of these abundance ratios were steeper across each spiral arm than the global variations. Torres-Peimbert and Peimbert (1971) have used abundances derived from planetary nebulae (PN) to derive abundance gradients. Type II PN - which are population I objects - are suitable for gradient determi-

nation because they are not affected by enrichment of helium due to their own stellar evolution. However, the observed N/H abundance ratio for PN of both type in solar neighbourhood is found to be larger than in HII regions by about a factor of four whereas O/H abundance ratio is similar. This result seems to favour the idea that PN are producing nitrogen without affecting their O/H ratio and that O/H ratio for them indicates the abundance of ISM at the time of formation of the parent stars. Table 1 lists a compilation of abundance gradients derived using HII regions and PN. The wavelengths of important emission lines for each element are also listed.

### 3.2 Stellar observations :

The first evidence of an abundance gradient in our Galaxy was obtained by van den Bergh (1958), who studied the distribution of Cepheids of different periods in the galactic disk. He found that the short-period Cepheids ( $P \sim 2-3$  days) predominate the region away from the galactic centre whereas Cepheids with longer periods ( $P \sim 7-9$  days) occupy a region closer to galactic centre. It has been already shown in the description of simple model that the abundance of heavy elements in the interstellar gas depends on the ratio of the mass of interstellar gas to the total mass of gas and stars and this ratio is known to be a function of galactocentric distance. Van den Bergh suggested that the dependence of Cepheid periods on distance from galactic centre result from a radial variation of abundance of heavy elements in the interstellar gas from which Cepheids were formed. Peimbert (1977) employed this idea to determine the O/H abundance gradient in the Galaxy by assuming that the O/H abundance derived from HII region is directly proportional to the Cepheid period. He calibrated this relationship by employing data on Cepheids in SMC and the Galaxy. Fernie (1968) had earlier derived a relation between galactocentric distance  $R$  and the Cepheid period with a slope  $\Delta \log P / \Delta R = 0.05 \text{ d kpc}^{-1}$ . An average value of  $\langle \log P \rangle = 0.97$  for the galactic Cepheids and  $\langle \log P \rangle = 0.5$  for SMC were reported by Arp and Kraft (1961). Peimbert and Torres-Peimbert (1976) had found a difference of 0.76 in  $\log (O/H)$  for the HII regions of solar neighbourhood and in SMC, which led Peimbert (1977) to derive  $\Delta \log (O/H) / \log P = 1.6$ .

Therefore,

$$\frac{\Delta \log (O/H)}{\Delta \log P} \times \frac{\log P}{\Delta R} = \frac{\Delta \log (O/H)}{\Delta R} = 1.6 \times 0.05 = -0.08 \text{ kpc}^{-1}.$$

Hartwick reported in 1970 that the ratio of the number of red to blue supergiants increases with increasing distance from the galactic centre. A similar phenomenon - when reported by Walker (1964) for M33 - was interpreted by van den Bergh as an effect of metallicity gradient. The argument is that the intrinsic brightness of red giants in metal-poor globular clusters is higher than that in metal-rich clusters (Sandage and Wallerstein 1960). Such an effect acting in supergiants would cause the

TABLE 1  
Summary of light element gradient in the galactic disk

	He/H	O/H	N/H	C/H	$N^+/S^+$	Source
Lines used	He I 4472, 6678, 5876, 7065	O I 6300 O II 3276, 7329, O III 4363, 5007	NI 5198, N II 5755, 6584	C II 4267	N II 6548, S II 6717, S III 6312,	6584 6731 9532
Objects						
H II					-0.04	1
H II	-0.02	-0.13	-0.023		-0.09	2
H II	0.0	-0.04	-0.10		-0.05	3
H II		-0.11	-0.11		-0.06	4
H II		-0.09	-0.12	-0.09	-0.05	5
H II		-0.10	-0.14		-0.05	6
PN	-0.02	-0.06	-0.18			7

(1) Sivan 1976 (2) Peimbert et al 1978 (3) Hawley 1978 (4) Talent and Dufour 1978 (5) Peimbert and Torres-Peimbert 1978 (6) Peimbert 1978 (7) Torres-Peimbert and Peimbert 1977.

metal-rich stars to be intrinsically fainter than those of lower metal abundance; since the intrinsically fainter stars would not be readily detected, one might reasonably expect this effect to produce a variation in the ratio ( $N_{\text{red}} / N_{\text{blue}}$ ) in the sense indicated by observations. Thus, Hartwick's observations also indicate a metallicity gradient in the Galaxy.

Janes and McClure (1972) derived a radial abundance gradient in the disk of our Galaxy from CN-band photometry of nearly 800 K giants. The CN feature measured by C (41-42) colour index is related to the  $[\text{Fe}/\text{H}]$  abundance. For a sample of K giants covering a galactocentric distance range 5—15 kpc they derived a radial abundance gradient  $d[\text{Fe}/\text{H}] / dR = -0.023 \pm 0.011$ . Janes (1979) used the DDO Photometry of distant K giants, and DDO and UBV photometry of 41 open clusters to estimate the variation of metallicity across the galactic disk. Mayor (1976), by an analysis of the kinematic and photometric properties of about 600 dF stars and 600 gG—gK stars derived a radial abundance gradient of  $-0.05 \text{ kpc}^{-1}$ , while Mayor deduced the metallicity of dF stars using u, v, b, y and  $\beta$  photometry to derive metallicity index in Stromgren's system, he used the metallicity of gG—gK stars published by Hansen and Kjaergaard (1971) using the narrow band photometry of Dickow et al (1970). The gradient quoted above is for the entire sample with the eccentricities ( $e$ ) of the galactic orbits of the stars in the range 0.05 — 0.4. For youngest stars of the sample with  $e$  in the range 0.05 to 0.10 the metallicity gradient is steeper:  $d[M/\text{H}] / dR = -0.10 \pm 0.02 \text{ kpc}^{-1}$ . A similar value is obtained by Hansen and Kjaergaard for sodium.

Using Washington colour photometry of a large number of Cepheids, Harris (1981) derived a gradient in metallicity  $-0.07 \text{ kpc}^{-1}$  covering a sample of 10 kpc (5 kpc — 15 kpc). The indices M—T1 and C—M used by them provide measures of the metallic line-strength between 4500A—5600A and metallic line plus CN and CH molecular bands between 3400A — 4500A. Panagia and Tosi (1980), analysed the HR diagrams of 17 selected open clusters and by fitting the observed diagrams with theoretical isochrones have estimated the chemical abundances of each cluster. Using this data, they derive a gradient of  $0.098 \pm 0.015 \text{ kpc}^{-1}$ . Systematic variation of the metal abundance with the galactic radius is also found from the analysis of the distribution of O type stars in the Sagittarius spiral arm (Panagia and Tosi 1981). Here, the use is made of the observation that among O type stars of main sequence the metal-rich stars are cooler than the metal-poor ones. Therefore, for the large sample of 211 O type stars the temperature gradient can be derived using the spectral type-temperature conversion of Underhill et al, (1979) which is then converted to a metallicity gradient using the ( $\Delta T_{\text{eff}}, \Delta Z$ ) relationship of Panagia and Tosi (1980)

Apart from these photometric estimates of metal abundance which are of lower accuracy, the more accurate abundance determinations based on high-resolution spectra and model atmosphere technique have also been tried in order to determine the abundance gradient in the galactic disk

Luck, Lambert and Bond have determined accurate abundances for a larger number of bright yellow supergiants and Cepheids. By combining the spectroscopically determined abundance data on supergiants and Cepheids, Luck (1982) has derived an abundance gradient which is somewhat steeper than other estimates. The relatively small range of 3 kpc in distance increases the uncertainty in the gradient derived by Luck. I have derived abundance gradient of iron by spectroscopic studies of selected Cepheids. The distance range covered in my study is 30% larger than that of Luck (1982), and the derived gradient agrees better with the photometric estimates. Such detailed analysis of individual stars should ultimately lead to more accurate results when the sample is enlarged to larger distances, and to larger number of stars. Also, such studies are indispensable for the calibration of a photometric reddening free abundance index.

A summary of abundance gradients derived from stellar observations is presented in Table 2. In the second column of the table, the photometric indices used and central wavelengths of important bands are also given.

As one could have noticed in the summary of the abundance gradient given by HII regions is steeper than that given by PN. This could result from (i) different O/H distribution of the ISM at the time of formation of the parent star or (ii) a different O/H in the shell from that in the original cloud from which the parent star formed. Comparing the O/H gradient derived from HII regions and Fe/H gradient from young stars, one gets the impression that the rate of enrichment of Fe has been different from that of oxygen and that Fe/H and O/H gradients are not directly comparable. Chevalier (1976) explains this discrepancy by suggesting that Fe enrichment is due to supernovae of type I while that of O is due to supernovae of type II.

#### 4. FURTHER OBSERVATIONAL CONSTRAINTS ON THE MODELS OF CHEMICAL EVOLUTION

##### (i) *The G dwarf problem*

Even though the simple model predicts an abundance gradient, it gets into difficulty in the solar neighbourhood itself because it predicts more metal-poor stars than observed. Better models have been developed that are vastly superior to the simple model not only in giving better fit to G dwarfs but also because they form part of a more comprehensive picture. In the models of Larson (1976), instead of assuming evolution in isolated zones, and infall of metal-poor gas is incorporated whereas the Metal Enhanced Star Formation model of Talbot and Arnett (1973) differs from the simple model in the assumption that stars are born systematically richer in heavy elements than the average ISM. Truran and Cameron (1971) suggest a model with variable initial mass function such that initially only large-mass stars were formed which resulted in prompt enrichment (PIE) of ISM. After the metallicity of ISM reached some



TABLE 2

Summary of different estimates of metallicity gradients  
derived from stellar observations

Object	Photometric Indices and Wavelength region	$-\frac{d(\text{Fe}/\text{H})}{dR}$	Source
Old disk F and G stars	Metallicity index $m_1$ in Stromgren's u v b y and $\beta$ system. These bands are centred at 3500, 4110, 4670, 5470, 4860 Å & narrow band photometry of Dickow central wavelength of the bands 3440, 3910, 4174, 4271, 4389, 4517 4973 Å	$0.04 \pm 0.03$	1
Young disk F and G stars	„ „	$0.10 \pm 0.02$	1
G and K dwarfs	Geneva photometric system, cen- tral Wavelength of the bands 3456, 4245, 4078, 4480, 5500Å	$0.05 \pm 0.02$	2
K giants and open cluster	CN index in DDO photometry	$0.023 \pm 0.01$	3a
	C (41-42) index and U-B colour in UBV photometric system	$0.05 \pm 0.01$	3b
Young cluster	By fitting HR diagrams with theoretical isochrones	$0.089 \pm 0.015$	4
O stars	By the study of temperature varia- tion of O type main sequence stars across the disk	$0.095 \pm 0.034$	5
Cepheids	Metallicity indices M-T <sub>1</sub> and C-M in Washington Photometric system the bands C M T <sub>1</sub> T <sub>2</sub> are centred at 3910, 5085, 6330 and 8050Å	$0.07 \pm 0.01$	6
Supergiants and Cepheids	High dispersion spectra in blue and red spectral region	$0.013 \pm 0.01$	7
Cepheids	High resolution spectra in 4300Å —4600Å	$0.05 \pm 0.01$	8

(1) Mayor 1976 (2) Grenon 1972 (3a) Janes and Meclure 1972  
(3b) Janes 1979 (4) Panagia and Tosi 1980 (5) Panagia and Tosi 1981 (6) Harris  
1981 (7) Luck 1982 (8) Giridhar 1983.

specific value, the subsequent evolution is assumed to occur in accordance with the simple model. The two-component disk-halo model of Ostriker and Thuan (1975) in which the processed material ejected by halo stars is accumulated in rapidly rotating disk, also comes under PIE category. However, these models do not require a variable IMF. All these models are fairly successful in accounting for the abundance gradient, and the essential physics that accounts for this particular observation is the same as in the simple model. The abundance gradient is attributed to the increased efficiency of star formation in the interior regions of the Galaxy as compared to the outer regions, which is symptomized by an inwardly decreasing ratio of the surface density of gas to the total surface density.

(ii) *The abundance ratio  $X_s/Fe$*

The simple model predicts the abundances of secondary elements to vary as the square of the primary element abundance i.e.  $X_s \propto Z^2$  where  $X_s$  is the abundance of secondary elements. Now, oxygen is a good representative of primary elements. If nitrogen is assumed to be secondary in origin then a relation of the type  $[N/O] = \alpha [O/H]$  with  $\alpha = 1$  is predicted by the simple model. However, from the data on several galactic HII regions, Peimbert (1978) derived a value of  $\alpha$  close to 0.4 in poor agreement with the theoretical prediction. A poor fit with observations is encountered even with more precise models that drop instantaneous recycling approximation. A possible explanation given by Peimbert (1978) is that in these objects the nitrogen is mostly of primary origin with a primary production close to  $\log (N/O) \sim -1.7$ .

Next we consider the heavier s-process elements. The s-process elements are the secondary elements formed via the process of slow neutron capture by heavy seed nuclei (mostly Fe). For the metal-deficient stars of halo population, Spite and Spite (1978) found the s-process element barium, and to certain extent yttrium, to be overdeficient. This over-deficiency decreases when Fe/H increases and becomes negligible for  $[Fe/H] > -1.5$ . From an analysis of a homogeneous group of old metal-poor F and G stars of the old galactic disk, Huggins and Williams (1974) found correlation between  $[S/Fe]$  and  $[Fe/H]$ . They interpreted this correlation as an evidence that heavier s-process elements of the ISM in the disk have increased more rapidly than the overall metal abundance during the time interval covered by the formation of these stars. However, Figure 1 shows the variation of  $[S/Fe]$  as a function of  $[Fe/H]$  for a sample of classical Cepheids (Giridhar 1983) which are young objects of disk population. It is obvious from the figure that  $[S/Fe]$  is not correlated with  $[Fe/H]$ . The simple model predicts S/H to vary as  $[Fe/H]^2$ . With the inclusion of PIE to solve the G dwarf problem, the abundance of s-process elements is not expected to be as fast as  $[Fe/H]^2$  but yet faster than  $[Fe/H]$ . In other words, a positive correlation between  $[S/Fe]$  and  $[Fe/H]$  is predicted. The correlation found by Spite and Spite for halo stars and Huggins and Williams for old disk stars are in agreement

with the simple model; but the lack of any correlation for young disk star shows inadequacy of the simple model in this case. Instead of a closed system, if the models with infall of metal-poor gas are considered then, since this infall produces dilution effects which counteracts the enrichment of ISM, the asymptotic variation of Fe/H and S/H are predicted. Therefore, the ratio S/Fe does not change after Fe/H and S/H have reached their asymptotic value. The lack of correlation between [S/Fe] and [Fe/H] for the young disk stars exhibits the effect of infall on the evolution of the galactic disk.

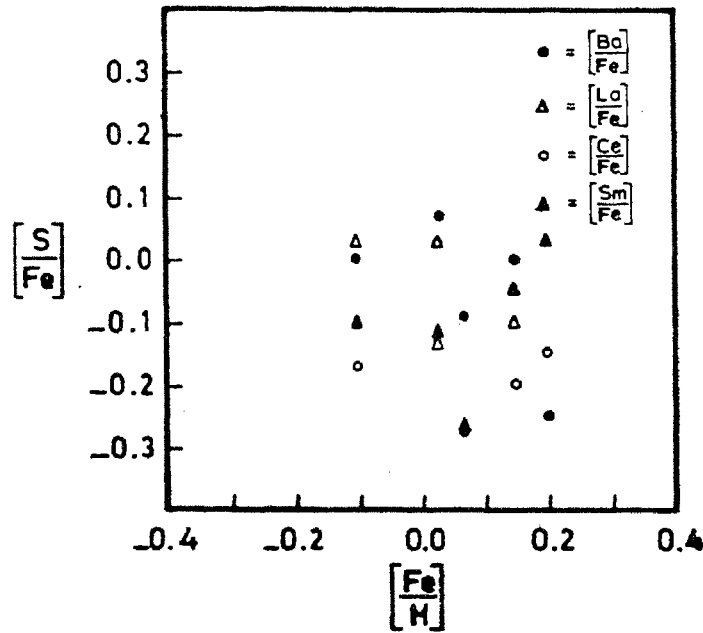


Figure 1. A plot of [S/Fe] vs [Fe/H] for five classical Cepheids (Giridhar 1983).

(iii) *The abundance gradient in the outer part of the galaxy :*

An interesting trend pointed out by Janes (1979) is that the abundance gradient becomes shallower towards the galactic centre while a steeper gradient is encountered towards anticentre. This implies a slower rate of chemical enrichment in the outer parts of the Galaxy. If we assume a continuous radial abundance gradient of the size ( $-0.05$ ) derived from the solar neighbourhood data, then it appears that the periphery of the galactic disk contains a very different stellar population from that of the solar neighbourhood. From the UBV photometry of the open cluster Berkeley 21 at a distance of 20 kpc from the galactic centre, Christian and Janes (1979) found that the colour-magnitude and the two-colour diagrams of this cluster resemble those of the clusters found in the Magellanic Clouds better than the galactic clusters. Other evidence of this similarity comes from the large concentration of carbon stars in the anticentre direction. Mould (1982) suggested that this well-known asymmetry in the galactic distribution of carbon stars is intimately related to the radial metallicity gradient, since carbon stars are mostly formed by dredge-up of the carbon on the upper Asymptotic Giant Branch in metal-poor composition. Another interesting link in the above idea is the

observation of Fuenmayor (1981) that the high surface density of carbon stars at 16 kpc from the galactic centre represents approximately the same fraction of the total mass surface density in this region (for an exponential disk) as the ratio of carbon stars in LMC to its total mass. This analogy with LMC is an interesting one. It implies a quite different evolutionary history for the outer disk from that of the solar neighbourhood. It will be interesting to extend to the outer part of the disk the experiments that have been conducted in the solar neighbourhood to determine the abundance distribution and the age-metallicity relation. This will provide additional constraints on the models of galactic evolution. The evidences of differences in mean metallicity from that observed in the solar neighbourhood opens up the possibility of radically different chemical histories for distant regions. In the development of enrichment models, processes like PIE or infall are evoked to match observations. These models do not predict with certainty the metallicity gradient that will be observed at different galactocentric radii. It is imperative to extend abundance surveys in the regions away from the solar neighbourhood because this will lead to a global theory of disk evolution.

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