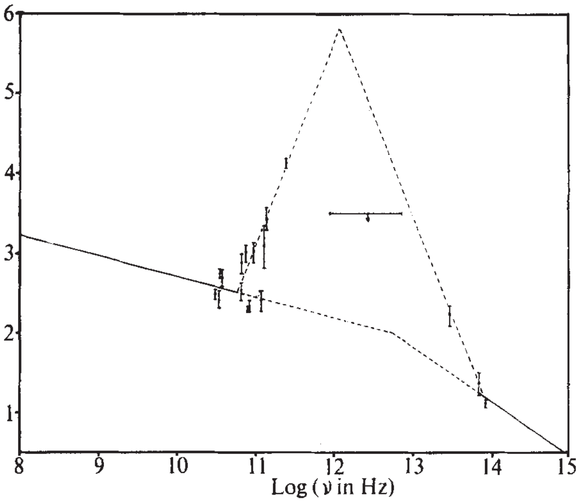

Fig. 2 Spectrum of the Crab Nebula showing two possible distributions in the far infrared based on the available millimetre and near infrared data. Well established regions of the spectrum are shown as solid curves. The integrated far infrared flux predicted by the upper curve is approximately sixty times greater than the upper limit obtained in this experiment.

spectrum over the spectral band used. Errors are difficult to assess but are estimated to be about ±25%.

Our beam size was too large to observe any structure in M 42. The total flux measured, however, agrees well with the value $(90\pm10)\times10^{-14}$ W cm^{-1} obtained by Low and Aumann[2] in the band from 50 μm to 300 μm using a somewhat larger field of view (~8 arc min).

The only previously reported measurement of the infrared source in NGC 2024 is due to Harper and Low[3] (HL) who employed an 8.4 arc min beam and give the flux as 42×10^{-14} W cm^{-2} in a much wider band extending from 45 μm to 750 μm. As HL also found the M 42 flux to be considerably higher with this system it is interesting to compare their value for the flux ratio M 42/NGC 2024 = 4.4 with the value of 4.2 obtained with our system in a narrower bandwidth.

Infrared and millimetre wavelength measurements of the Crab Nebula are summarized in Fig. 2. The millimetre measurements are controversial[4], but extrapolation of the "high" millimetre points and also the near infrared measurements through the recently reported excess at 10 μm (ref. 5) indicates a spectrum peaking in the far infrared. The slope of 2.5 through the millimetre points would fit a model involving synchrotron self absorption[6], whereas the spectral index of 2.5, appropriate to extrapolation through the point at 10 μm, is the same as that obtained by Scargle[7] from measurements in the visible before correction for extinction. Such a spectral distribution, however, leads to a dramatic increase in the far infrared flux compared with that predicted by using the "normal" interpolation between the radio and visible data, shown as the lower dashed curve in Fig. 2.

Our aim in including the Crab Nebula in the scanning programme was simply to determine whether or not a flux of this magnitude was present in the far infrared. Whereas integration of the extrapolated curve gives rise to a flux approximately sixty times our detectable limit, no signal was in fact observed and the upper limit of 3,000 f.u. obtained was set by the maximum noise measured in the sections of seven overlapping scans covering a region extending ±3 arc min in elevation and ±20 arc min in azimuth about the centre of the Crab. This area was chosen to give generous allowance for any pointing errors.

Table 1 Summary of Results

Source	α (1950)	δ (1950)	F_{40-350} (10^{-14} W cm^{-2})
M 42	5 h 32.8 m	−5° 25′	106
NGC 2024	5 h 39 m	−1° 55′	25
M 1	5 h 31.5 m	+21° 59′	<2

We conclude that if the high millimetre points are in fact correct, the turnover in the spectrum must occur in the millimetre or submillimetre region and not in the far infrared. The upper limit obtained also gives some indirect support for the model which has already been proposed to explain the 10 μm excess in terms of thermal reradiation by dust grains and which predicts a peak of ~10^3 f.u. around 25 μm (ref. 8).

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Effect of Infalling Matter on the Heavy Element Content of a Galaxy

I HAVE considered[1] some of the possible implications of infall of intergalactic matter in galaxies, a process which was proposed by Oort[2] to explain the 21 cm observations of high velocity hydrogen "clouds" in our Galaxy. It was pointed out that infall of matter may have a number of important consequences for the structure and evolution of galaxies. In this communication I shall consider in more detail one of these possible consequences, namely the effect of continuing infall of matter on the composition of the interstellar medium and the Population I component of a galaxy. I shall show that in the presence of infalling matter the heavy element content of the interstellar material will tend to approach a constant value which is independent of both the infall rate and the early history of the galaxy, and depends only on stellar evolution processes.

Hydrodynamic calculations of the formation of a spherical galaxy[3] suggest that during the later stages in the formation of a galaxy (which can last for 10^{10} yr or longer) there is approximate equality between the rate of infall of gas and the rate at which gas is transformed into stars, so that the amount of interstellar matter in the galaxy remains approximately constant with time. Also estimates of the infall rate and of the star formation rate in our Galaxy[1] yield comparable numbers and are consistent with the hypothesis that these processes are in balance. I shall therefore make the simplifying assumption that the total gas content of the galaxy remains constant with time. If M_g is the total mass of interstellar gas in the galaxy (or in some smaller volume such as a column of 1 pc^2 cross section perpendicular to the galactic plane) and if M_Z is the total mass of heavy elements contained in this gas, the fractional abundance of heavy elements is $Z=M_Z/M_g$. Because M_g is assumed to be constant, the rate of change of the heavy element abundance Z is given by

$$\frac{dZ}{dt} = \frac{1}{M_g}\frac{dM_Z}{dt} \tag{1}$$

Several processes contribute to the increase or decrease of the interstellar heavy element content M_Z. If the infalling intergalactic matter contains little or no heavy elements, the infall of additional matter will in itself produce no change in M_Z. I shall make the simplifying but perhaps reasonable assumption that all of the heavy element enrichment occurs through the ejection of matter from massive stars whose lifetimes are much shorter than the age of the galaxy; the rate of heavy element production is then proportional to the rate of formation of massive stars, which is in turn proportional to the total star formation rate. If dM_*/dt is the rate at which gas is transformed into stars, and α is the fraction of the material going into star formation which is re-ejected within a short time in the form of heavy elements, the rate of addition of heavy elements to the interstellar medium is then $\alpha(dM_*/dt)$. The interstellar heavy element content M_Z will also be depleted by the star formation process itself; because a fraction Z of the material going into stars is in the form of heavy elements, the rate of removal of heavy elements from the interstellar medium is $Z(dM_*/dt)$. We can then write

$$\frac{dM_Z}{dt} = \alpha\frac{dM_*}{dt} - Z\frac{dM_*}{dt} \tag{2}$$

In deriving this equation it is implicitly assumed that mixing of the interstellar material is very efficient, so that the heavy element abundance Z is everywhere the same.

Equations (1) and (2) can be combined to yield

$$\frac{dZ}{dt} = \frac{\alpha - Z}{\tau} \tag{3}$$

where

$$\tau = \frac{M_g}{dM_*/dt} \tag{4}$$

is the time scale for turnover of the interstellar medium, which I have estimated[1] to be of the order of 3×10^9 yr for the present interstellar medium in our Galaxy. If the turnover time τ is, for the moment, assumed to be independent of time, integration of equation (3) is elementary and yields

$$Z = \alpha + (Z_0 - \alpha)\, e^{-t/\tau} \tag{5}$$

where Z_0 is the heavy element abundance at time $t=0$. In this case the heavy element abundance Z approaches the asymptotic value α after a time $\gtrsim \tau$, and it becomes nearly independent of both Z_0 and τ. More realistically, the turnover time will not be constant over the lifetime of a galaxy but will be shorter during the earlier phases of its formation when the infall and star formation processes proceed most vigorously; the approach of Z to the asymptotic value α will then be even more rapid than would be predicted by equation (5) with $\tau \sim 3\times10^9$ yr.

If the infalling intergalactic matter contains a finite heavy element abundance Z_i, it can be shown that equation (5) still applies (in the case of constant τ) except that α is replaced by $\alpha+(1-\beta)Z_i$, where β is the fraction of the matter going into star formation which is re-ejected from evolving stars within a time $\lesssim \tau$.

It is significant that the asymptotic heavy element abundance is independent not only of time, but is also independent of any initial element synthesis in the galaxy (represented here by Z_0) and independent of the infall rate and turnover time τ (provided that τ is significantly shorter than the age of the galaxy). The asymptotic heavy element abundance α depends only on the stellar mass spectrum and on stellar evolution processes, and may therefore be expected to have considerable universality. This may account for the observed fact that, to a first approximation, the heavy element abundance Z seems to be much the same everywhere in the universe, except in the oldest (Population II) stars and stellar systems.

In principle, the value of the "universal" heavy element abundance α could be predicted if enough were known about the final evolution of massive stars; at present, however, this subject does not seem to be well enough understood to allow such a prediction to be made with confidence. It does not seem implausible, however, to suppose that $\sim 1/3$ of the mass going into star formation is re-ejected from evolving massive stars, and that $\sim 1/10$ of the ejected matter consists of heavy elements; these numbers would be consistent with the observed "universal" heavy element abundance of $Z \approx 0.03$.

In this communication, I have considered only the simplest possible assumptions, which will not always be satisfied. Refinements to this simple model might be able to explain some of the observed variations in the heavy element content of galaxies. The observed increase in Z in the central regions of many galaxies[4] may, for example, be explainable if star formation in the nucleus of a galaxy produces a higher proportion of massive stars than elsewhere; this would lead to a higher value of α in the nucleus. Also, incomplete mixing of the interstellar medium might allow variations in the heavy element abundance by factors of 2 or more, as appears to be observed in the galactic disk.

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Ionospheric Shock Front from Apollo 15 Launching

IONOSPHERIC perturbations observed at Fort Monmouth, New Jersey, over a distance of more than 1,200 km following the launch of Apollo 14 were attributed[1] to the arrival of an atmospheric shock front which splits[2] at ionospheric heights into ion acoustic and normal acoustic modes. An opportunity to repeat these observations was provided by the launching of Apollo 15 on July 26, 1971, at 0834 EST. Ionograms were taken at our station (74 : 07 : 52 W longitude; 40 : 23 : 25 N latitude). Ionograms taken simultaneously at Wallops Island (75 : 29 W longitude; 37 : 51 N latitude) were made available by courtesy of National Oceanic and Atmospheric Administration (NOAA). We converted all ionograms to true-height.

A difference was noted with respect to the Apollo 14 observations: the ionosphere during Apollo 14 launching was a winter-afternoon ionosphere, denser and higher than the July-morning ionosphere on Apollo 15 day. Consequently, it was not possible to observe from Apollo 15 the differences in the altitude ranges ascribed to ion acoustic and normal acoustic modes observed from Apollo 14.

The simultaneous observations at Wallops Island and Fort Monmouth permit comparison of the effective group velocities of related signals. We again assume signal production by near northward travel[1] of the wake front created by the rocket. The travelling distance of the front to Wallops Island is estimated to be about 1,000 km, and about 1,275 km to Fort