Fermi National Accelerator Laboratory

FERMILAB-Pub-85/179-A
December 1985

THE LOCAL DENSITY AND MORPHOLOGY DEPENDENCE OF THE GALAXY LUMINOSITY FUNCTION

Jacek Chołoniewski [1]

Mirosław Panek [1,2]

1. Copernicus Astronomical Center, Warsaw
2. NASA/Fermilab Astrophysics Group

Abstract

We obtain the luminosity function (LF) for a set of samples of galaxies from the CfA North catalogue. The criteria of selection of samples are the local density (range – more than 3 orders of magnitude) and/or the morphology. No difference in the LF is found for the samples of different density. The LF of the E+S0 galaxies is steeper in the high density places than in the low. These results may indicate that the LF determined at the moment of the galaxy formation may be only weakly influenced by the phenomena present in dense places and that the processes determining the LF are almost independent on the density of environment, with possible exception for E+S0 galaxies. The meaningful difference in the LFs is found for early and late spirals.

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

I. INTRODUCTION

The problem of the universality of the luminosity function (LF) of galaxies is important for the theories of galaxy formation and for various cosmological calculations. It is now well known (Dressler 1984) that the morphology of galaxies is correlated with the density of their environment. In a natural way the question of the local density and morphology dependence of LF arises. Holmberg (1974) found that LF depends on the morphology. A number of studies were carried out to investigate LF for cluster and field galaxies. However, the samples were usually poor and defined in a way making direct comparisons difficult. No conclusive evidence for a LF dependence on the density of the sample was found. See Felten (1985) for a review. Our aim is to measure LF of the various samples of galaxies from the northern part of the CfA catalogue (Huchra et al. 1982). The criteria for the selection of the samples were the local density of the environment of galaxies and their morphological type. The nearest neighbour (NN) algorithm was used to select the galaxies lying in the different mean density volumes.

II. THE METHOD OF LUMINOSITY FUNCTION DETERMINATION

We used the new method of determination of the LF, $\Phi(M)$ (M – absolute brightness), the number density function $\rho(\mu)$ (μ – distance modulus), and the average number density of galaxies, n. The details of the method are given by Chołoniewski (1985). The method is designed for magnitude-limited samples and assumes neither homogeneity of the galaxy distribution, nor any analytical parametrization of the shape of the LF. It works properly for samples such that absolute brightness and location of galaxies in space are uncorrelated. The samples selected for their density and/or morphology had the above property at about 60% confidence level while the level for the complete sample was 95% (the suitable test is described by Chołoniewski 1985).

The method gives results in the form:

$$\Phi_i = \frac{1}{\Delta} \int\limits_{M_{i-1}}^{M_i} \Phi(M) dM \quad , \qquad M_i = M_{min} + \Delta i$$

$$\rho_j = \frac{1}{\Delta} \int\limits_{\mu_{j-1}}^{\mu_j} \rho(\mu) d\mu \ , \qquad \mu_j = \mu_{min} + \Delta j$$

where Δ is the bin width, equal throughout this paper to 0.5 .

Schechter's (1976) parameters α and M_* have been obtained by the least squares fit to Φ_i $(i = 1, ..., A)$ values using their full covariance matrix that is also supplied by the method.

We computed the distances assuming pure Hubble flow for the radial velocities, corrected for the Sun's orbital movement $(H_0 = 100 km \cdot s/Mpc)$. No correction for galactic extinction was applied. Our results are for:

$M \in [-21.5, -15.5]$

$\mu \in [29.5, 35.0]$ or $D \in [8, 100] Mpc$

III. THE SAMPLES OF GALAXIES

The galaxies from the CfA north catalogue were selected according to the density of their neighbourhood. We adopted here the simplest algorithm of the density determination – the NN distance. We found this distance, R for each galaxy. However, the catalogue is magnitude-limited and the distances were scaled (Huchra and Geller 1982):

$$R = R_{uns} \, \phi(D)^{\frac{1}{3}}$$

where R and R_{uns} are scaled and unscaled NN distances for the galaxy at distance D. The function $\phi(D)$ is the selection function normalized to 1 at the distance $D = 40Mpc$:

$$\phi(D) = \frac{\int_{-\infty}^{M_D} \Phi(M) dM}{\int_{-\infty}^{-18.5} \Phi(M) dM} \quad , \qquad M_D = 14.5 - \mu$$

where $\Phi(M)$ is the LF found for the complete CfA North sample – 1832 galaxies. $\phi(D)$ is the number of galaxies at distance D with $m < 14.5$ (included in the catalogue) in comparison with this number at $D = 40Mpc$.

The reliability of this method of selection correction is uncertain because the physical dimensions of e.g. clusters of galaxies do not scale with distance. Some distant galaxies lying in low density volumes are assigned to the high density sample. This can lower the differences (if any) in LFs for the samples but obviously cannot generate them.

We used the scaled NN distances R to divide the galaxies into groups having the NN at $R_1 < R < R_2$. To avoid edge effects, the galaxies with the NN distance larger than the distance to the borders of the catalogue volume were excluded. To investigate the LF dependence on the density of the neighbourhood we obtained four subsamples:

1. 208 galaxies with the NN closer than 0.5 Mpc.
2. 429 galaxies with the NN distance beetwen 0.5 Mpc and 1 Mpc.
3. 506 galaxies with the NN distance between 1 Mpc and 2 Mpc.
4. 280 galaxies with the NN distance greater than 2 Mpc.

(The sum of the 1 and 2 samples is roughly the same as the sample of groups of galaxies from Geller and Huchra 1983). We find the volumes of these samples as the sums of the volumes of the spheres around each galaxy, with the radius equal to the unscaled NN distance.

The de Vaucouleurs' type indexes from the CfA catalogue were used to obtain morphological subsamples:

5. 169 elliptical galaxies (T = −7, −6, −5, −4)

6. 321 lenticular galaxies (T = −3, −2, −1)

7. 1082 spiral galaxies (T = 1 to 9, 20)

8. 574 early spirals (T = 1 to 4)

9. 360 late spirals (T = 5 to 9)

Then the subsamples of different density were selected for different morphological types:

10. 221 E and S0 galaxies with the NN distance $<$ 1 Mpc.

11. 180 E and S0 galaxies with the NN distance $>$ 1 Mpc.

12. 343 S galaxies with the NN distance $<$ 1 Mpc.

13. 501 S galaxies with the NN distance $>$ 1 Mpc.

The numbers of galaxies in the samples used for the determination of LFs were smaller than the numbers given above because of the requirements of the method.

IV. RESULTS

Our results are presented on fig.1-8 and in Tab. 1. All LFs found in this work were well described by the Schechter's (1976) form of LF (parameters α and M_*).

The LF of all CfA north galaxies (fig.1) was used to scale the NN distances. Our method of LF determination is not the best for this sample. However, the form of the LF used for scaling is of the minor importance for the final results.

The LFs for the four samples of different density (fig.2) are found to be quite similiar in the limits of errors. This means that the differences between them cannot be large – the small differences could easily be erased in our selection correction method. This result indicates that the processes determining the LF do not depend strongly on the density.

The LFs for the separate morphological classes show some differences. Spiral (fig.3) and lenticular (fig.4) galaxies have the LFs close to each other, but LF for elliptical galaxies (fig.5) posesses less steep bright ends. Another interesting result is the difference between the LFs of early (fig.6a) and late (fig.6b) spirals. The latter have a much steeper faint end, and in the mean are darker.

The spirals show no differences in the LF for the subsamples of high/low density (fig.7). Such differences are found at almost one-sigma level for the appropriate subsamples of E+S0 galaxies (fig.8) (we add them to represent the family of low gas content and low angular momentum galaxies. This is allowed despite differences in their LFs, because they posses similiar density distributions).

We expect that interactions between galaxies in dense places can influence their properties. There are some arguments that tidal stripping in close encounters has more efect on galaxies of smaller angular momentum (E, S0) than on spiral galaxies (Miller 1983). The bright ones are destroyed and their dark remnants should populate the dense places. This would be seen in the LF – the high density LF of E+S0 galaxies would be steeper than the LF of E+S0 low density galaxies. However, our results (if real) indicate the reverse. It is also not probable that the mergers cause the deficiency of the dark E+S0 galaxies in dense places because the mergers act mainly on the bright galaxies (Heiligman and Turner 1980). This may mean that processes responsible for the observed difference operated in the moment of the formation of galaxies and that subsequent evolution of galaxies in clusters is of minor importance.

ACKNOWLEDGEMENTS

M.P. is grateful to the Astrophysics Group at Fermilab for its hospitality during completion of this work.

REFERENCES

Chołoniewski, J., 1985, submmited to Mon. Not. R. astr. Soc.

Dressler, A. 1984, Ann. Rev. Astr. Astrophys., **22**, 185.

Felten, J. E. 1985, preprint.

Geller, M. J., and Huchra, J. P. 1983, Ap. J. Suppl., **52**, 61.

Heiligman, G. M., and Turner, E. L. 1980, Ap. J., **236**, 745.

Holmberg, E. 1974, Ark. Astron., **5**, 305.

Huchra, J., Davis, M., Latham, D. W., and Tonry, J. 1983, Ap. J. Suppl., **52**, 89.

Huchra, J. P., and Geller, M. J. 1982, Ap. J., **257**, 423.

Miller, G. E. 1983, Ap. J., **268**, 495.

Schechter, P. 1976, Ap. J., **203**, 297.

TABLE CAPTION

Table 1. Luminosity function parameters (α, M_*) and the average number density of galaxies (n) with their errors. N denotes the number of galaxies that were used directly for computations.

FIGURE CAPTIONS

Figures 1-8. Logarithms of luminosity function of galaxies (left) and of number density versus distance modulus (right). Their values lie in the middle of the standard confidence intervals that are denoted by error bars. Curves show the Schechter's fits. If two or more LFs are present on one figure it means that the highest concerns the highest density sample etc.

Table 1.

	Sample	N	α		M_*		n (D<100) (M<-16)	/%/	[10^{-3} Mpc^{-3}] (D<80) (M<-18.5)	/%/
	All	1242	-1.09	.06	-19.25	.07	51.	17	9.9	12
1	0 <NN<0.5	161	-1.00	.15	-19.22	.21	18320.	52	3696.	34
2	0.5<NN< 1	350	-1.12	.10	-19.48	.15	1630.	28	566.	22
3	1 <NN< 2	394	-1.30	.11	-19.47	.15	391.	29	84.	21
4	2 <NN	179	-1.31	.26	-19.13	.24	74.	54	11.	32
5	E	122	-1.04	.20	-19.87	.39	2.4	40	0.65	25
6	S0	230	-0.95	.13	-19.14	.15	15.	45	3.3	35
7	S	749	-1.08	.08	-19.32	.09	20.	21	5.2	13
8	S-early *	260	-1.07	.16	-19.36	.18	9.2	32	2.0	29
9	S-late *	178	-1.50	.17	-19.69	.30	7.6	50	1.0	46
10	E+S0 NN<1	175	-0.87	.16	-19.13	.21	948.	45	236.	29
11	E+S0 NN>1	133	-1.20	.22	-19.47	.22	24.	49	6.5	35
12	S NN<1	272	-1.03	.11	-19.52	.17	717.	28	284.	20
13	S NN>1	362	-1.18	.13	-19.28	.15	44.	31	8.5	20

* - results for m<14

POSTAL ADDRESS PAGE

Jacek Choloniewski

Copernicus Astronomical Center

Polish Academy of Sciences

ul. Bartycka 18

00-716 Warszawa, Poland

Miroslaw Panek

Copernicus Astronomical Center

Polish Academy of Sciences

ul. Bartycka 18

00-716 Warszawa, Poland

and

NASA/Fermilab Astrophysics Group

MS 209

Fermilab

P.O. Box 500

Batavia, IL 60510, U.S.A.

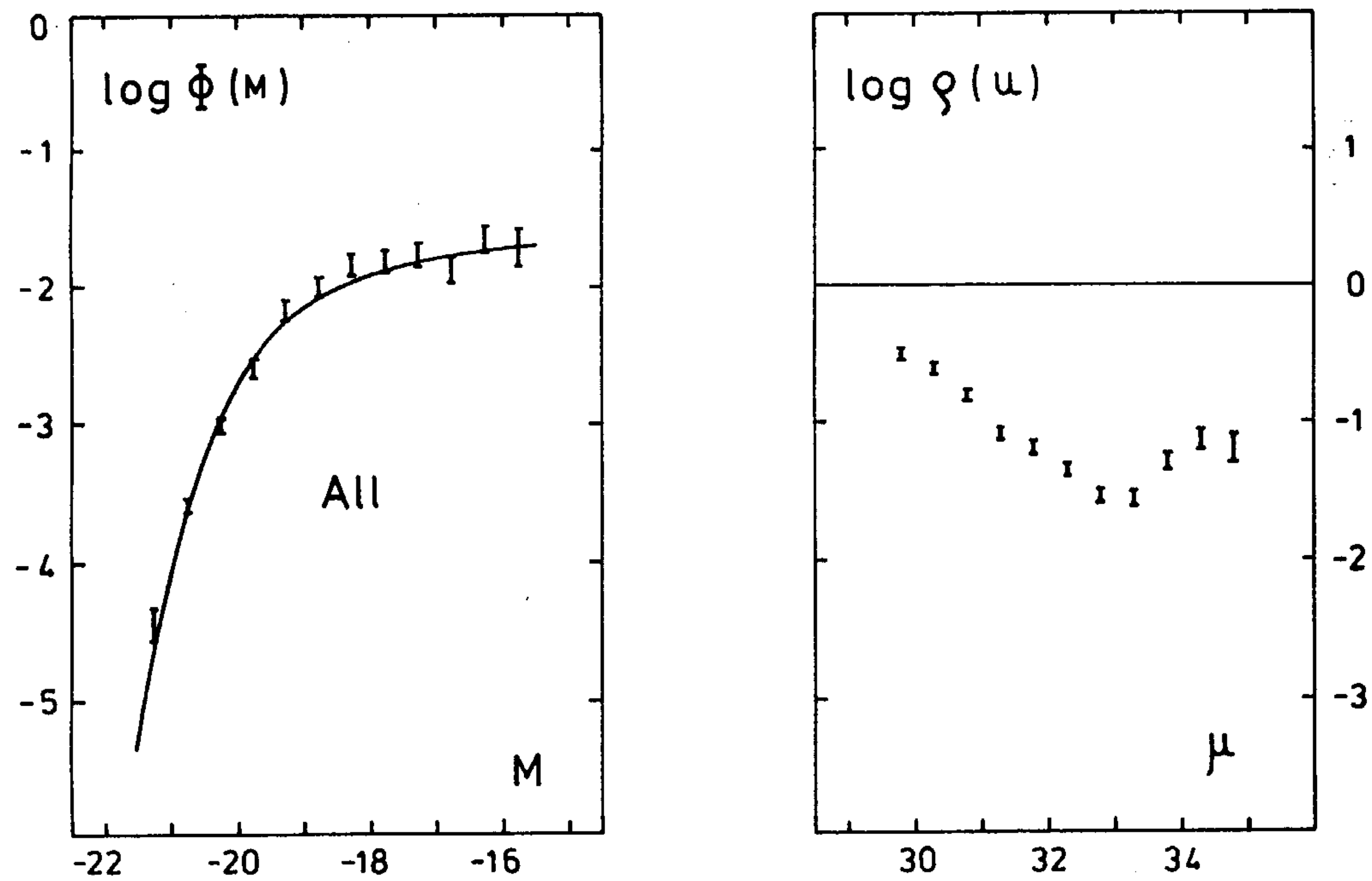

fig. 1

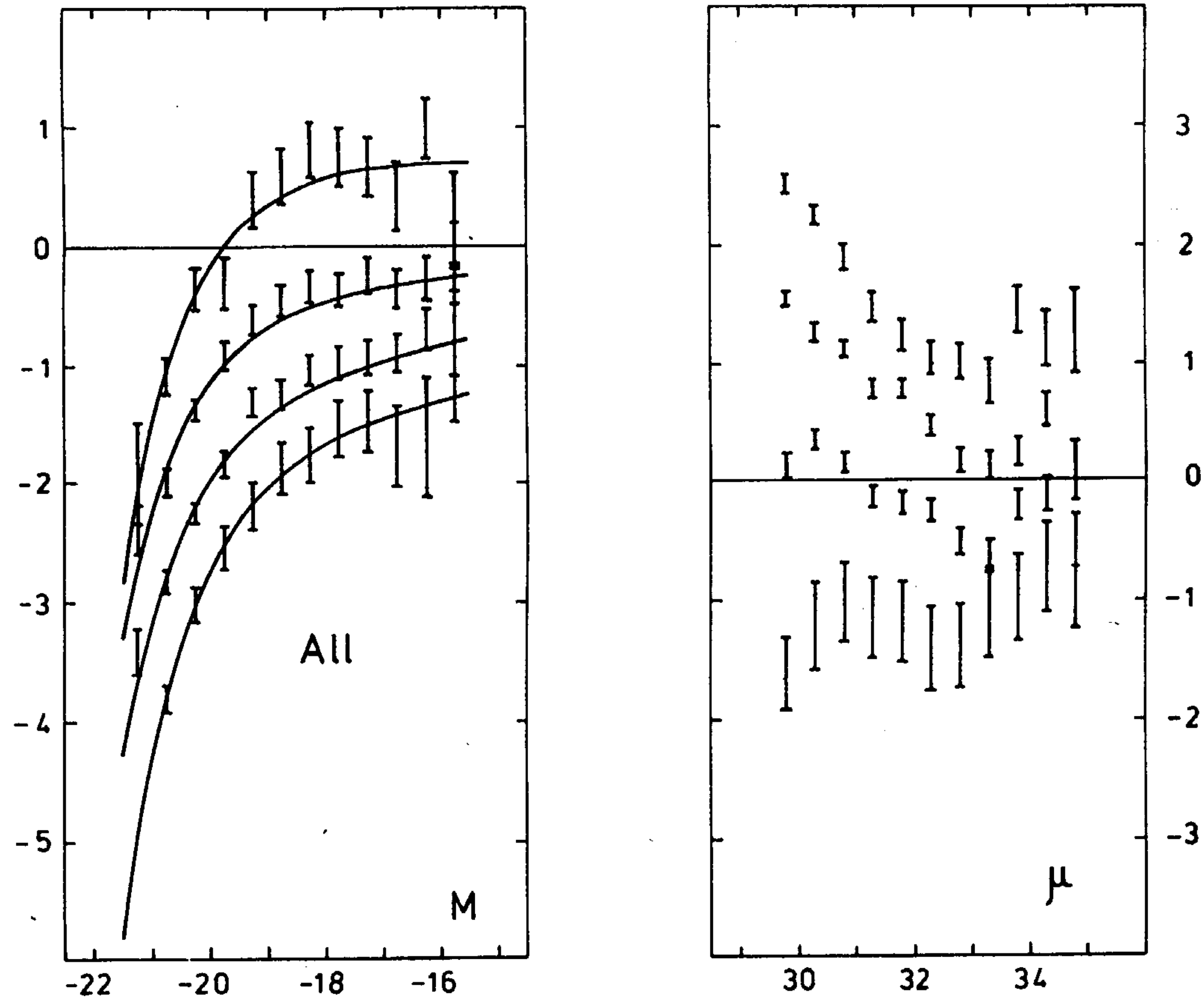

fig. 2

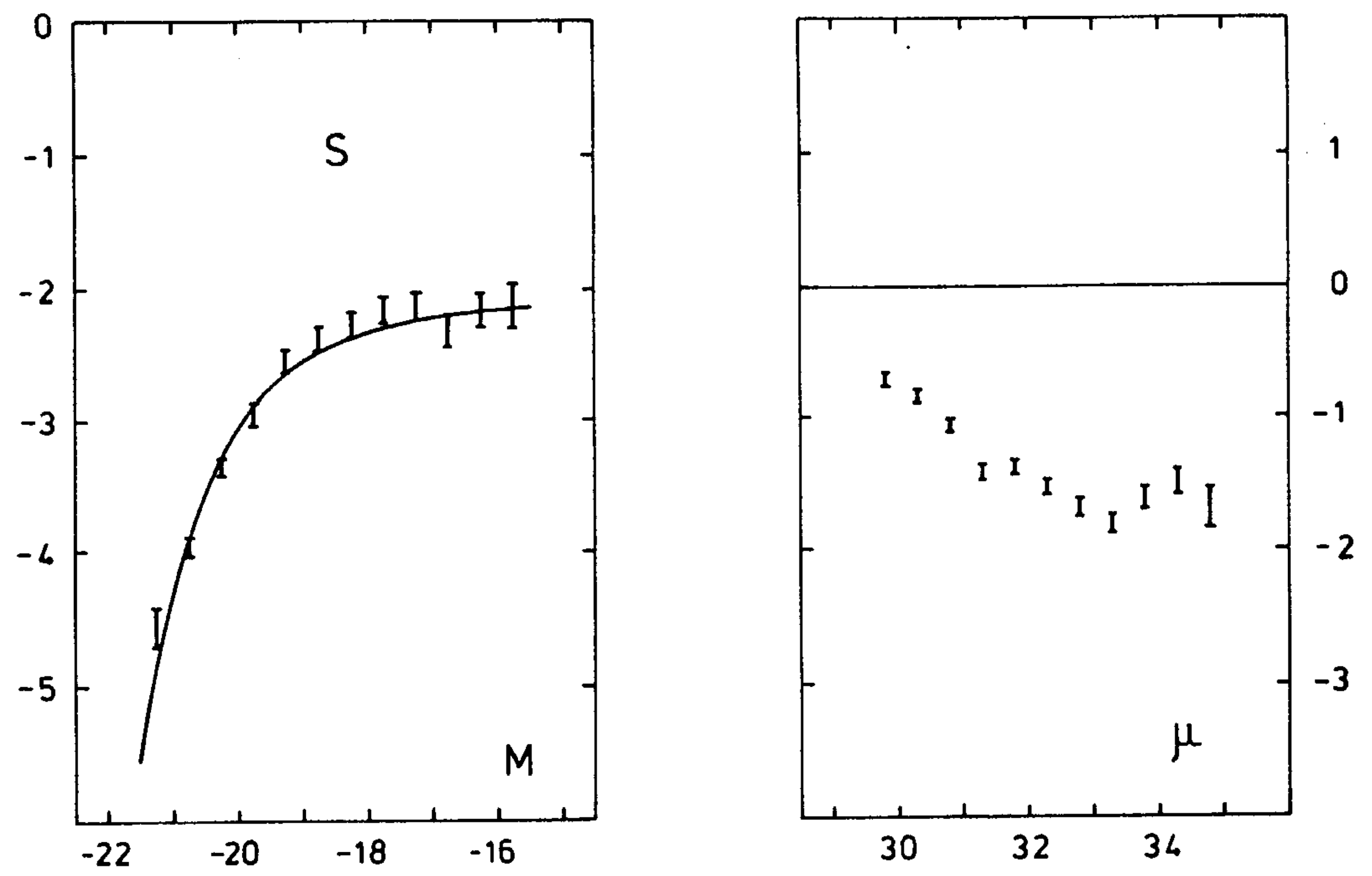

fig. 3

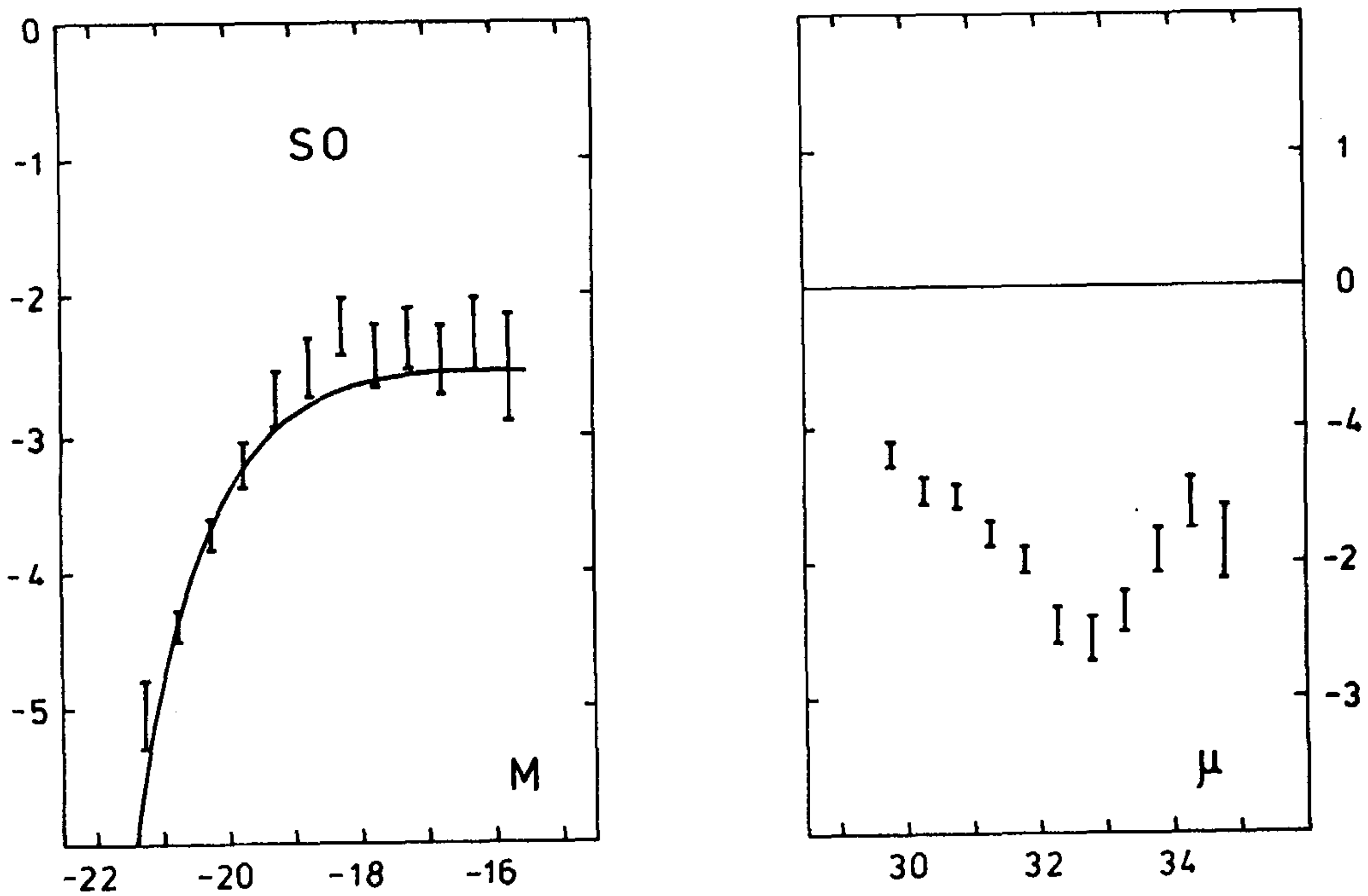

fig. 4

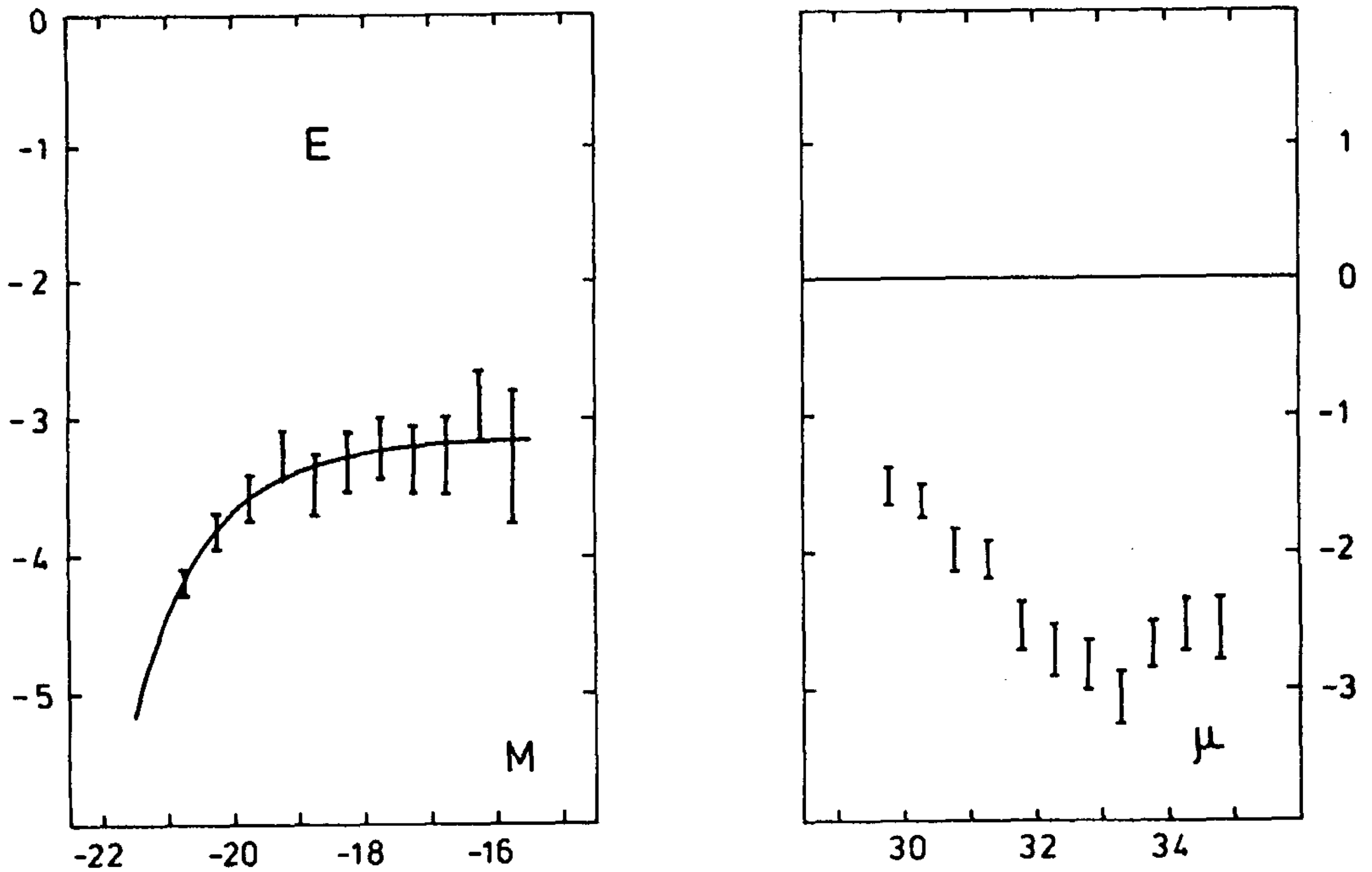

fig. 5

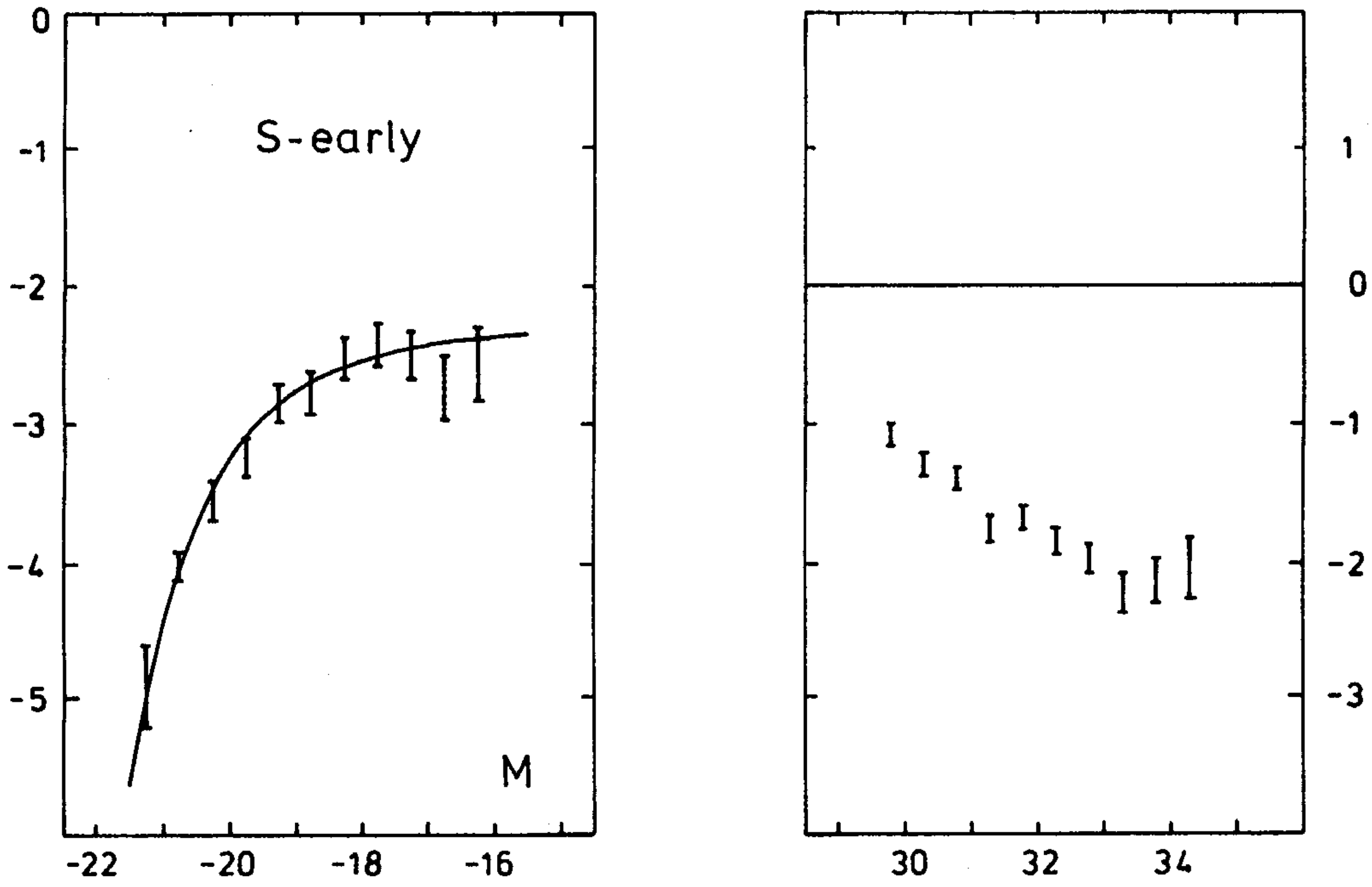

fig 6a

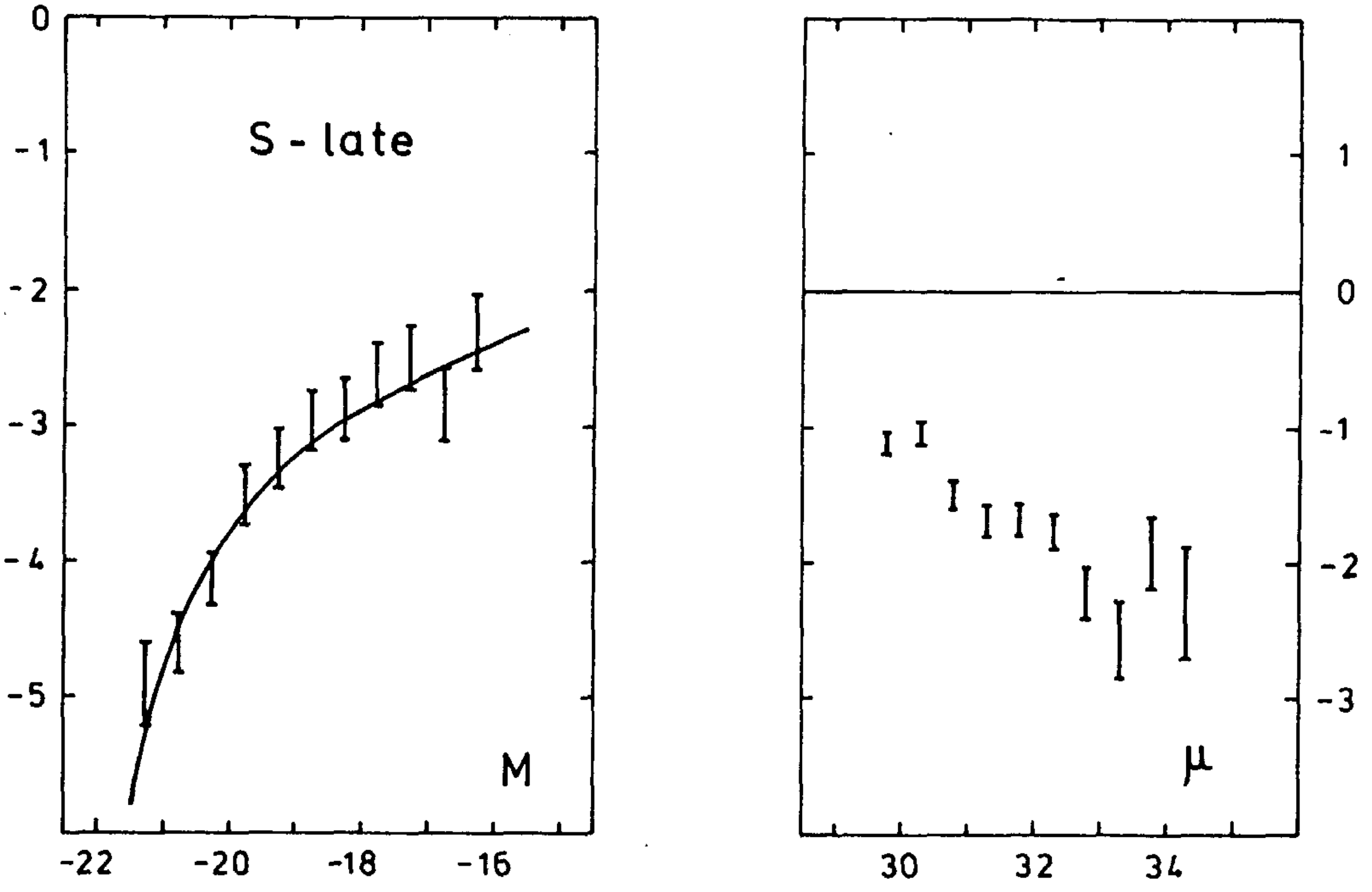

fig 6b

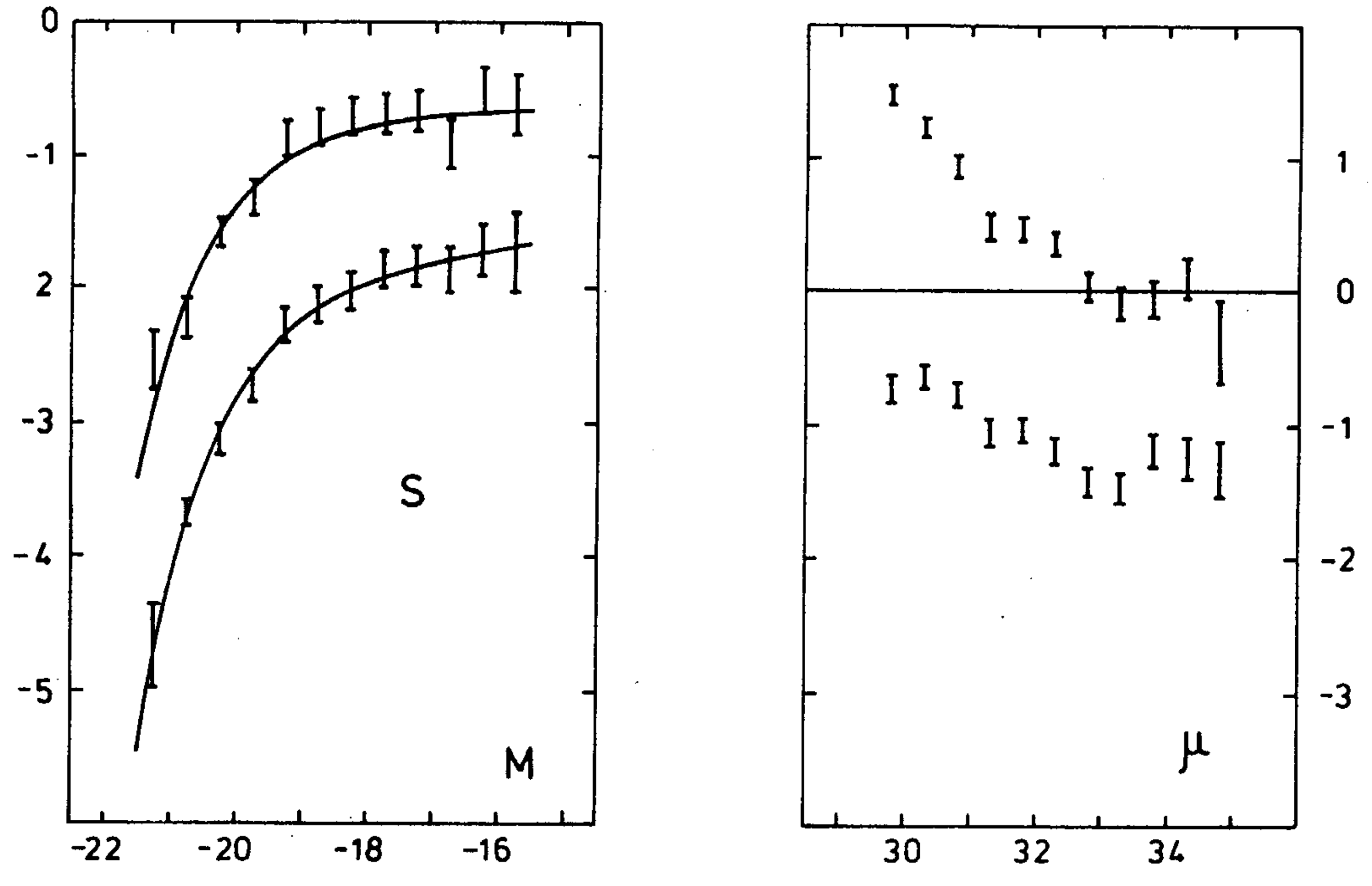

fig. 7

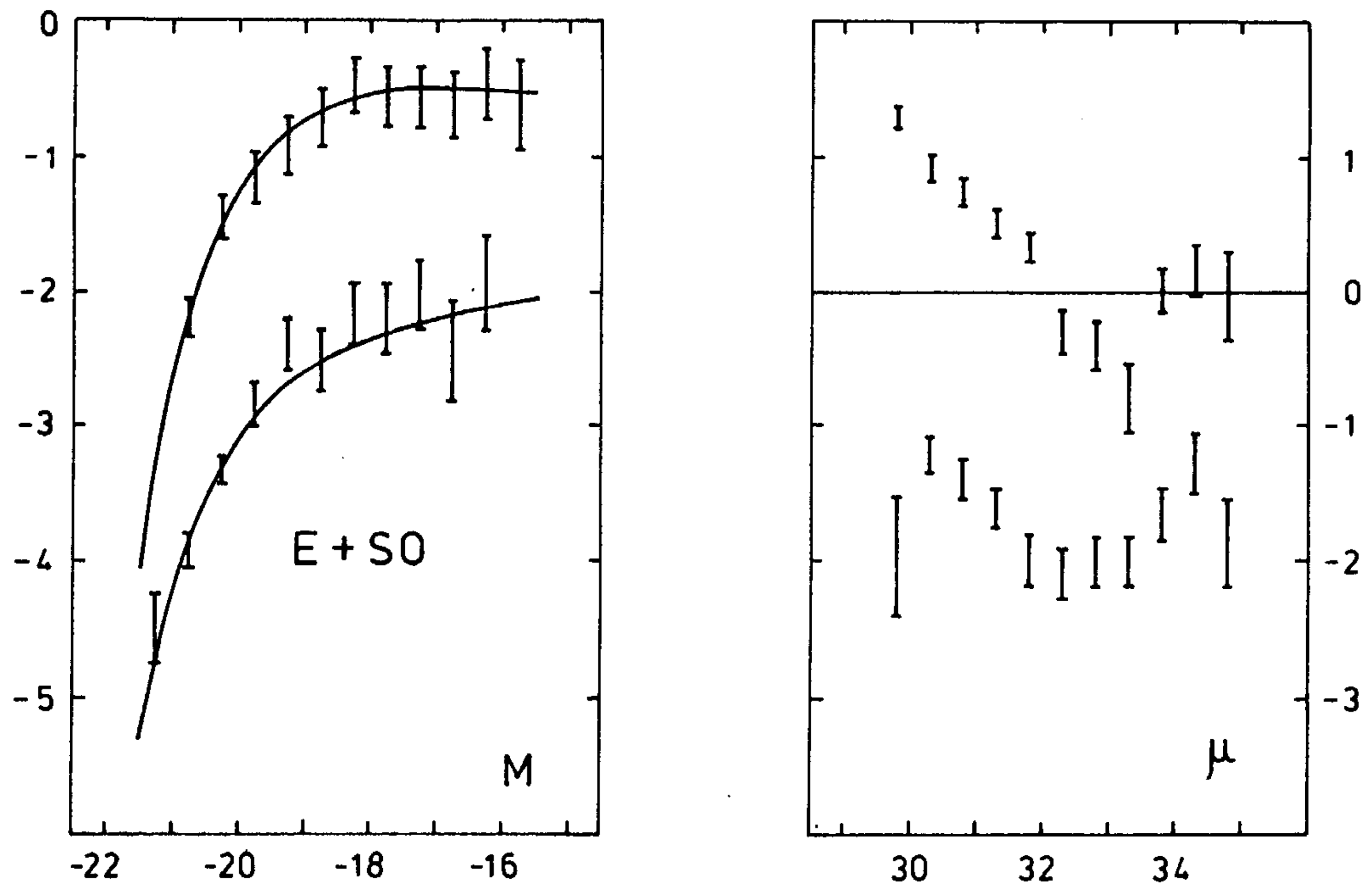

fig. 8