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Internal motions in the open star clusters NGC 654 and 6087

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Abstract. Proper motion data have been used to study the internal kinematics in open star clusters NGC 654 and 6087. No dependence of the intrinsic dispersion in proper motion on stellar mass and radial distance from the cluster centre has been observed. Velocity isotropy has been observed in both the clusters.

Key words : Internal motion—open clusters—stellar dynamics

1. Introduction

Proper motion measurements are a powerful technique for the study of internal motions in open star clusters because they provide velocity information in two orthogonal directions and also have the advantage of being available for relatively large number of stars located at varying distances from the cluster centre and having different masses. Such studies have recently been made for some open star clusters (*cf.* Jones 1970, 1971; McNamara & Sanders 1977, 1978, 1983; McNamara & Sekiguchi 1986; Sagar & Bhatt 1989). For the study of internal motions in open star clusters, accurate determination of proper motion components with estimates of the associated errors are required. This is because both the intrinsic dispersion and the dispersion due to errors contribute to the observed dispersion in proper motion components. Internal kinematics have been studied here for NGC 654 (C 0140 + 616) and NGC 6087 (C 1614 — 577) based on proper motion data given by Stone (1977) and King (1982) respectively. Other general information about these clusters is given in table 1.

2. Cluster members

The proper motion studies in these cluster regions have probably been able to segregate members from field stars because the histogram of proper motion membership probability p of all stars in each cluster region indicates that most of them belong to two well separated groups; one with low p ($\leqslant 10\ \%$) and other with high p ($\geqslant 70\ \%$). To reduce the probability of inclusion of field stars in the sample, only stars with $p \geqslant 50$ % have been considered. For a good number of such members UBV photometric data, and for a few radial velocity data, are available in the catalogues of Mermilliod (1984a, b, 1986). Non-members on the basis of these data have also been excluded from the subsequent analysis. Because of the requirement of better estimation of proper motions for the study of internal motions in open star clusters, we have rejected those member stars whose such data have uncertainties of more than the mean error of the cluster proper motion data which is 0.07 and 0.15 arcsec century^{-1} for NGC 654 and 6087 respectively. The number of sample stars N finally used in the present analysis is listed in table 1.

Table 1. General information and intrinsic dispersion in the proper motion components

Cluster	Distance* (pc)	log age	Number of samples	$\sigma_{\mu x}$ (arcsec century^{-1})	$\sigma_{\mu y}$ (arcsec century^{-1})
NGC 654	2250	7.2	37	0.05 ± 0.01	0.04 ± 0.01
NGC 6087	820	7.7	43	0.05 ± 0.03	0.09 ± 0.02

*From Jones & Adler (1982).

3. Intrinsic proper motion dispersions

The intrinsic proper motion dispersions for all sample stars are estimated using the procedure given by Jones (1970) and described in detail elsewhere (Sagar & Bhatt 1988a, b). The results listed in table 1 indicate that the orthogonal components $\sigma_{\mu x}$ and $\sigma_{\mu y}$ of the intrinsic proper motion dispersion are equal within their associated uncertainties. Consequently, the weighted mean σ_μ of the intrinsic dispersion in proper motion components have been used to study their dependence on stellar mass and radial distance from the cluster centre. The cluster centre is defined as the point of maximum stellar surface density (Sagar *et al.* 1988).

In order to study the dependence of intrinsic velocity dispersion on stellar mass, we have divided the entire sample into only two V magnitude bins so that each bin can have a statistically significant number of stars, generally more than 20. The V magnitude range of the bin has been converted into the mass range by assigning appropriate masses to their main sequence position (Schmidt-Kaler 1982). The apparent distance moduli used here are taken from Janes & Alder (1982). The intrinsic dispersion in proper motion σ_μ and number of sample stars N for each bin of a cluster are given in table 2. It can be seen from this table that the σ_μ of different mass groups of a cluster are the same within their associated errors.

To study the radial dependence of σ_μ, we again divided the entire sample stars into two radial bins and estimated σ_μ for each bin. The results and number of sample stars are again given in table 2. One can easily notice from table 2 that there is no statistically significant radial dependence of σ_μ in both the clusters under discussion. The values of σ_μ for different radial bins of a cluster are the same within their associated errors.

Table 2. Dependence of intrinsic dispersion in proper motion on stellar mass and radial distance from the cluster centre

Cluster	Radius (arcmin)	Range in V(mag)	Mass ($M/M_\odot$)	σ_μ (arcsec century^{-1})	N
NGC 654		7.0-13.0	20.0–7.4	0.04±0.01	15
		13.0-14.0	7.4–5.1	0.04±0.01	22
	$r < 3$	—	—	0.03±0.01	20
	$3 \leqslant r \leqslant 30$	—	—	0.05±0.01	17
NGC 6087		7.5-10.3	10.3–3.8	0.09±0.02	22
		10.3-12.5	3.8–1.8	0.07±0.02	21
	$r < 12$	—	—	0.10±0.03	22
	$12 \leqslant r \leqslant 44$	—	—	0.09±0.02	21

4. Velocity anisotropy

To gain some information about the anisotropy of the velocity distribution, we have computed the components of each star's proper motion and error along two areas : one along the cluster centre (the radial direction) and the other perpendicular (the tangential direction). The intrinsic proper motion dispersions are then computed along these axes using all the sample stars and also as a function of radius by dividing the sample stars into bins as described in the last section. The results are given in table 3. A comparison of the intrinsic proper motion dispersion in the radial direction $\sigma_{\mu r}$ with that in the tangential direction $\sigma_{\mu t}$ indicates that $\sigma_{\mu r} \approx \sigma_{\mu t}$ in the clusters studied here, if one considers their associated errors, indicating the absence of any significant velocity anisotropy. Such results have also been reported by Sagar & Bhatt (1989) for NGC 2287, 2669, 3532, 4103 4755, 5662 and IC 2391.

Table 3. Radial dependence of the radial and tangential proper motion dispersions

Cluster	Range in radius (arcmin)	$\sigma_{\mu r}$ (arcsec century^{-1})	$\sigma_{\mu t}$ (arcsec century^{-1})	N
NGC 654	$r < 3$	0.03±0.02	0.03±0.02	20
	$3 \leqslant r \leqslant 30$	0.05±0.02	0.06±0.01	17
	$0 \leqslant r \leqslant 30$	0.04±0.01	0.04±0.01	37
NGC 6087	$r < 12$	0.09±0.03	0.05±0.04	22
	$12 \leqslant r \leqslant 44$	0.09±0.03	0.07±0.03	21
	$0 \leqslant r \leqslant 44$	0.09±0.02	0.06±0.03	43

5. Discussion

We now discuss the results obtained above regarding the different aspects of internal kinematics of the open clusters.

Equipartition of energy

The study of the dependence of σ_μ on stellar mass and radius reported in section 3 indicates that there is no radial and mass dependence of σ_μ in both the clusters. Such relations are also observed in some other well studied open clusters (see McNamara & Sekiguchi 1986; Sagar & Bhatt 1989). Clusters studied here have ages $< 10^8$yr (see table 1), a typical dynamical evolution time for the system. Hence, they may not be dynamically relaxed. Therefore, equipartition of energy might not have yet taken place amongst the members of the clusters studied here. Whether this is the reason for the observed radial and mass independence of σ_μ or not is unclear because theoretical predictions concerning the relationship between stellar mass and velocity are subject to a number of uncertainties. The effects of encounters with molecular clouds, dynamical evolution, galactic tidal forces, and vestiges of star clusters initial formation conditions could well be present in the velocity distributions with star clusters. Under these circumstances, the simple energy equipartition relation that the velocity dispersions of two mass groups are inversely related to the square root of their average mass ratio may not be valid for all the clusters. The effect of galactic tidal field is to yield a flattened global velocity-mass relation.

Intrinsic dispersion in velocity

The weighted mean intrinsic dispersion of the proper motion components given in table 1, σ_μ in arcsec century^{-1} has been converted into one-dimensional intrinsic velocity dispersion σ_V in km s^{-1} using the relation σ_V (km s^{-1}) = 48.5 D(kpc) σ_μ (arcsec century^{-1}) where D is the distance to the cluster, taken from table 1. The resulting values are 4.9 ± 1.1 and 3.1 ± 0.7 km s^{-1} for the open star clusters NGC 654 and 6087 respectively. These estimates are in fair agreement with the values obtained recently using the precise (error $\leqslant 1$ km s^{-1}) radial velocity measurements for some open clusters (see Mathieu 1986; Sagar & Bhatt 1988). Thus the one dimensional internal velocity dispersions observed in the clusters studied here are typical of other clusters (~ 3 km s^{-1}).

6. Conclusions

Internal kinematics based on proper motion data have been studied in open clusters NGC 654 and 6087. Though not of very high precision, they are adequate to estimate internal motions and study their dependence on stellar mass and radial distance from the cluster centre. Intrinsic dispersions are found to be independent of stellar mass and radial distance in both the clusters. The finding of independence on σ_μ on mass indicates that the combined effect of the various processes (see section 5) acting on a cluser tends to make σ_μ independent of mass. We have observed velocity isotropy in both the clusters.

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