Galactic Centre

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Introduction

In 1918 Harlow Shapley [4] published a paper outlining observations made while continuing his work on the Milky Way globular cluster (GC) system. Analysis of 69 globular clusters showed a marked skew in distribution that could not easily be reconciled with contemporary views on the structure of the galaxy. To calibrate the distance to each GC Shapley used the newly discovered luminosity function for Cepheid variable stars. At the time, only 30 GC distances were known but from these Shapley determined a fairly strong relationship between their apparent size and distance. Extrapolating from this size-distance relationship to the other 39 clusters, and assuming the GCs centred on the galaxy, Shapley determined a direction and distance to the galactic centre. His calculations removed the Earth from its assumed central location within the Milky Way and shifted it some 20,000 parsecs from centre. While the result is no longer considered numerically accurate, it was a paradigm shift of a similar ilk to that of Copernicus in the 15th century.

This project aims to emulate this early work on the distribution of GCs using modern imagery and a larger sample of the Milky Way clusters. The cluster system will be mathematically reconstructed from derived relative distances so that a centroid can be determined.

Method

The method to be used for this project is:

- Determine list of candidate globular clusters.
- Source imagery for these clusters from Digitized Sky Survey (DSS).
- Inspect imagery and remove images that cannot be assessed visually.

- Using the *psfmeasure* task from the NOAO *nmisc* IRAF package determine a Full Width Half Maximum value for each image in arc seconds.
- Calculate a relative distance for each cluster using the small angle formula. This is a simpler method than that used by Shapley, who determined a curved fit to known distances from which to extrapolate, but it removes the need to use modern distance estimates for some sample of the GCs.
- Plot the globular cluster distribution on a series of graphs.
- Determine and plot the centroid of the cluster distribution.

For this analysis the following assumptions will be made about the Milky Way globular clusters:

- All the clusters are roughly the same absolute diameter, that is their apparent size is directly related to their distance. Without actually knowing the diameter this allows a comparison of distances expressed in terms relative to the shared diameter.
- All the globular clusters have comparable masses. This assumption is made to allow determination of a GC distribution centroid from a generalised equation for the centroid of N-particles. Without this assumption, either the true masses or some other method of determining the centroid would be required.

Results

Harris [2] provides a comprehensive list of data for the Milky Way GCs which was used to identify globular clusters for analysis. Harris' distance and size information was ignored with the exception of a few chosen values used to calibrate the relative distance scale. Imagery was available for all 147 objects identified in Harris' data, see Table 3. 143 images were drawn from the DSS 2nd generation red plates. NGC 6366 was sourced from DSS 1st generation imagery because it was not available in 2nd generation. First generation imagery was used for NGC 6229, NGC 104, and NGC 5139 for reasons discussed below. All images were 15 arcminute squares with the exception of NGC 104 and NGC 5139 which filled the smaller frame and were sourced as 30 arcminute images.

During image retrieval, Harris' declination coordinate for NGC 104 was found to be 1.2 seconds of arc different from coordinates returned from the SIMBAD search engine used by the DSS server. The reason for the difference is unclear but, given the size of NGC 104, it will not have adversely affected measurements. The SIMBAD coordinates were used for all calculations.

Preliminary visual inspection of the images revealed a number (39, 26.5%) that were unsuitable for measurement. These clusters were predominantly late additions to the family and only visible at infrared wavelengths or too sparse to define a boundary. The clusters are listed in Table 4 with a comment regarding their unsuitability.

Image analysis was undertaken using the Image Reduction and Analysis Facility (IRAF) and, in particular, the *psfmeasure* task provided in the National Optical Astronomy Observatories' (NOAO) *nmisc* package. In an iterative process, *psfmeasure* determines the centre of the radial brightness profile for the image, fits a cubic spline to the profile, and determines the radius at which brightness drops to half the maximum value. The reported figure is twice this radius and is known as the full width at half maximum (FWHM). Each GC is centred on its image providing *psfmeasure* with a starting approximation for the centre. Figure 4 shows a sample *psfmeasure* analysis for a NGC 1904.

The *psfmeasure* output FWHM values, scaled to provide measurement in arcseconds, are shown in Table 3. The large pixel count of the 2nd generation NGC 104 and NGC 5139 imagery proved difficult to analyse with IRAF so first generation imagery was substituted. The loss of resolution in reverting to first generation imagery for these two clusters is not considered to substantially affect the measurements being made. First generation imagery was used for NGC 6229 because the 2nd generation image was close to a photographic plate boundary resulting in distortion of the measurement.

A number of clusters required manual intervention to determine a FWHM measurement. Table 3 highlights these objects with an M (Manual) in the Method column. Reasons for measurement difficulty include close proximity of bright foreground objects, sparse cores, noisy image backgrounds, and failure of the automated process to converge. In cases where the manually driven electronic measurement could not be made reliably a manual estimate was made. While the consistency of these figures may be lower than those made by automated means there's little reason to treat these figures as substantially less reliable for the approximate calculations being made.

The small angle formula (Equation 1), is rearranged to provide the distance (d) in terms of diameter (D) and angular diameter (α in arcseconds) (Equation 2). The assumption of uniform physical diameters allows the use of these relative distances are the basis of galactic centre determination. Relative distances for the surveyed clusters are included in Table 3.

$$D = \frac{\alpha d}{206265} \quad (1)$$

$$d = \frac{206265 D}{\alpha} \quad (2)$$

To facilitate determination of the direction and relative distance of the galactic centre the polar RA and declination coordinates combined with

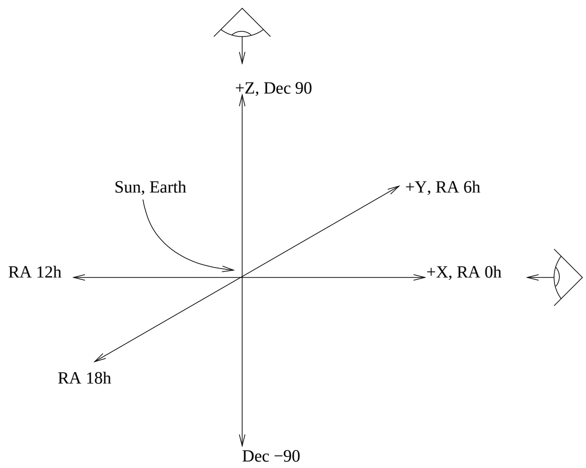


Figure 1: The Cartesian coordinate axes used for centroid determination. Viewing directions are shown for the two distribution plots.

the relative distance were converted to a Cartesian coordinate system. The right-handed system (Figure 1) has positive X in the direction of RA 0h and positive Z in the direction of the north celestial pole. X, Y, and Z coordinates for each cluster are presented in Table 3. Figures 2(a) and 2(b) show the cluster distribution when projected onto various planes. Clearly the centre of the distribution lies in the third quadrant in RA and south of the equatorial plane.

More precise centroid determination was achieved using a standard equation for the centre of mass of an ensemble of N particles [5]:

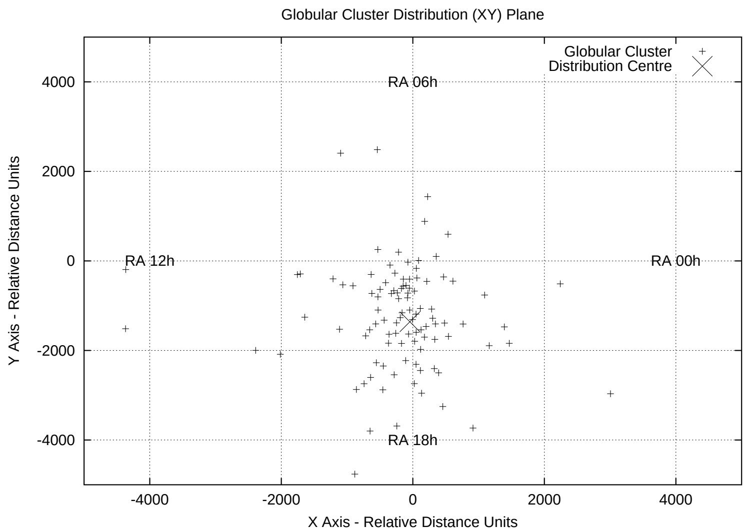
$$\mathbf{R}_0 = \frac{\sum_{i=1}^{N} m_i \mathbf{r}_i}{\sum_{i=1}^{N} m_i}$$

The assumption of uniform GC mass ($m_i = 1$) reduces the equation to a simple average of the position vectors ($\mathbf{r}$). This leads to the result shown in Table 1 and plotted on Figures 2(a) and 2(b). The determined point is near the boundary of constellations Saggitarius, Ophiuchus, and Scorpius.

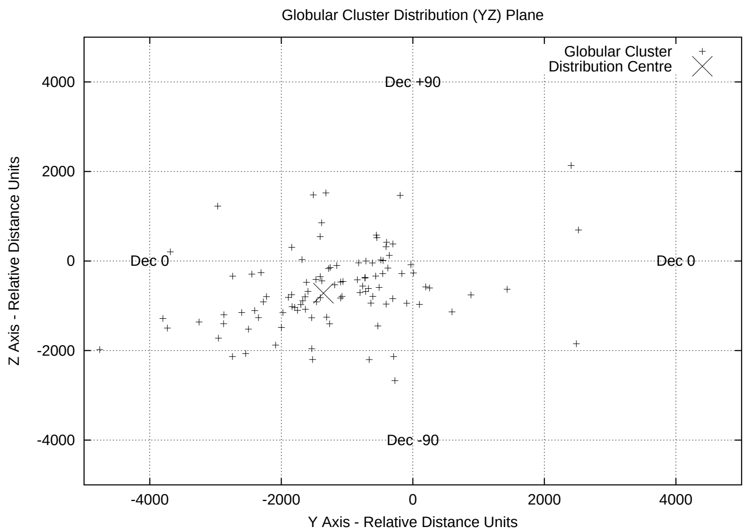
Centre coordinates	x=-45.8 y=-1359.1 z=-718.9
Right Ascension	17 hours 52 minutes 16.7 seconds
Declination	-27 degrees 51 minutes 41.9 seconds
Distance	1538.2 relative units

Table 1: Centre point of the globular cluster distribution.

The IAU defined a galactic coordinate system in 1958 [1]. The galactic north pole was defined as being the direction of RA $12h$ $49m$ Decl $27.4°$



(a) Projection the equatorial (XY) plane, looking toward the south celestial pole with RA 0h to the right.



(b) Projection onto the plane through RA 6h and the celestial poles (YZ), looking toward RA 12h with RA 6h to the right.

Figure 2: Projection of the globular cluster distribution onto two Cartesian planes. For clarity clusters with X, Y or Z > 5000 units are not shown.

in B1950 coordinates. This direction, converted to J2000 coordinates for consistency (Table 2), defines a normal to the galactic plane and thereby allows determination of a plane equation and relative distances from the plane. A plot of GCs on a plane through the galactic centre is shown in Figure 3; the galactic north pole is up and RA 12h is to the right. The plot is quite symmetrical about the centre due to the averaging process used to determine the centroid and the even spread in all directions. The centroid does not seem to have be unduly skewed by the presence of a few outliers at extreme distance. Clearly, the Sun is not central to the distribution. A zone of avoidance either side of the galactic plane on the same scale that Shapley [4] highlighted is not visible in the plot, but there does seem to be a small area reasonably free of clusters. This is possibly because modern instruments have improved our ability to see clusters near the plane.

NED Coordinate and Extinction Calculator Results		
Input: Equatorial B1950.0		
RA or Longitude	DEC or Latitude	PA(East of North)
192.25000000	27.40000000	0.000000
12h49m00.00000s	+27d24m00.0000s	
Output: Equatorial J2000.0		
192.85948402	27.12829637	359.932159
12h51m26.27616s	+27d07m41.8669s	

Table 2: Conversion of galactic north pole direction from B1950 to J2000 coordinates.

All distances calculated thus far are in relative terms. The relative scale can be calibrated using a GC chosen on the basis of similarity of distance to the centroid, NGC 6171 at 1556.8 units, with a modern distance, provided by Harris [2], of 6.4 kiloparsecs (kpc). Using this calibration leads to an actual distance to the centre of 6.3 kpc (20.5 klyr). On the same scale, the Sun is approximately 80 pc to the north of the galactic plane.

Conclusions

The rudimentary approach, assuming uniform physical size of Milky Way globular clusters, has lead to an estimate of the direction of the centre of the galaxy remarkably close to a more modern value of approximately RA 17h 45ms Dec -28d 56m ([3], translated to J2000 frame).

The determined direction of the centroid shows that the majority of GCs excluded from the analysis (Table 4) on the grounds of invisibility lie in the general direction of the denser portions of the galaxy. The phenomenon of interstellar extinction may be damping the visible portion of the emitted

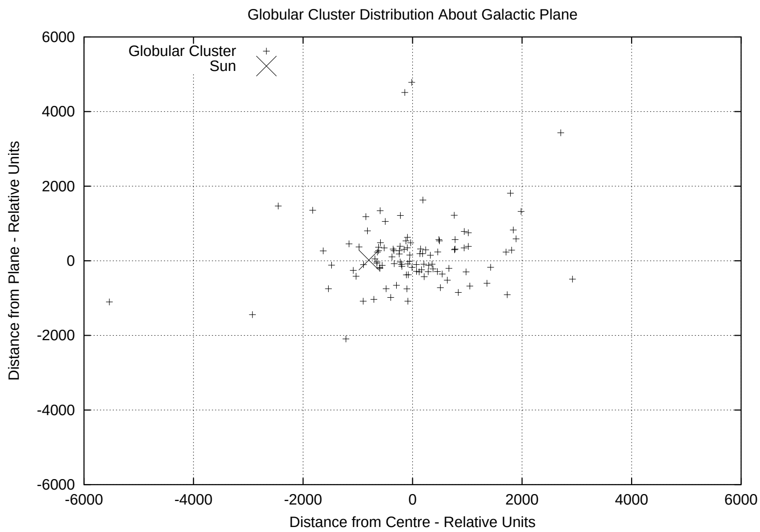


Figure 3: Plot of GCs in relation to the calculated galactic centre. Up is toward the galactic north pole and right is toward RA 12h. Clusters further than 6000 units from the centre have been omitted for clarity.

spectrum from these objects, and it seems reasonable to conclude they're reasonably distant. Their omission from analysis, although unavoidable, may be skewing the distribution in favour of the few distant objects (e.g. NGC 288) that lie well away from the galactic bulge.

On the face of it, the determination of distance has lead to a value comparable to modern estimates of 8 kpc. Unfortunately, the choice of cluster for calibration makes a large difference in absolute distances. If the closest cluster, NGC 5139 at 115.5 relative units, is used then the galactic centre is at the vastly different absolute distance of 70.5 kiloparsecs. Alternatively, the furthest, NGC 288 at 14420 units and 8.3 kpc, leads to a value of only 885 parsecs. The disparate nature of these estimates indicates that the assumption of uniformity of size or mass is erroneous, probably both.

This approach to determining the galactic centre's location is sufficient to demonstrate that the centre is not near the Earth as models at the start of the twentieth century assumed. The distribution of globular clusters in the galactic halo is also highlighted as is symmetry about the galactic plane. Precise distance, direction, and distribution determination would require more data about actual distance and size of globular clusters.

References

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Acknowledgements

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Table 3: Milky Way Globular Cluster Data.

Cluster	RA J2000	Dec	Method	FWHM (arcsecs)	Relative Distance	X	Y	Z
NGC104	00h 24m 5.2s	-72d 04m 49.9s	A	733.3	281.3	+86.8	+9.2	-267.4
NGC288	00h 40m 17.0s	+02d 45m 24.0s	A	14.3	14420.1	+14181.5	+2518.7	+693.5
NGC362	01h 03m 14.3s	-70d 50m 53.6s	A	198.8	1037.7	+355.3	+100.6	-969.8
NGC1261	03h 12m 15.3s	-55d 13m 0.5s	A	148.4	1389.8	+535.6	+596.2	-1135.4
AM1 (ESO201-10)	03h 55m 2.7s	-49d 36m 52.0s	A	21.5	9598.2	+3305.7	+5450.1	-7175.9
Pal2	04h 46m 5.9s	+31d 22m 51.0s	A	29.0	7116.8	+1925.4	+5762.6	+3705.9
NGC1851	05h 14m 6.3s	-40d 02m 50.2s	A	175.2	1177.2	+179.5	+884.4	-756.0
NGC1904 (M79)	05h 24m 10.6s	-24d 31m 27.3s	A	130.2	1583.6	+226.1	+1434.8	-630.8
NGC2298	06h 48m 59.2s	-36d 00m 19.2s	A	65.6	3144.8	-539.7	+2486.4	-1848.2
NGC2419	07h 38m 8.5s	+38d 52m 54.9s	A	60.7	3399.2	-1098.8	+2407.2	+2133.8
NGC2808	09h 12m 2.6s	-64d 51m 46.2s	A	317.5	649.7	-218.2	+196.4	-579.6
NGC3201	10h 17m 36.8s	-46d 24m 40.4s	A	244.4	844.0	-532.7	+255.2	-602.9
NGC4147	12h 10m 6.2s	+18d 32m 31.0s	A	44.8	4608.4	-4365.0	-192.6	+1465.5
NGC4590 (M68)	12h 39m 28.0s	-26d 44m 34.9s	A	104.7	1969.5	-1754.9	-305.2	-840.3
NGC4833	12h 59m 35.0s	-70d 52m 28.6s	A	204.3	1009.6	-347.7	-92.5	-943.3
NGC5024 (M53)	13h 12m 55.3s	+18d 10m 9.0s	A	153.3	1345.3	-1214.0	-399.9	+419.5
NGC5053	13h 16m 27.0s	+17d 41m 51.9s	A	42.5	4853.8	-4369.2	-1514.0	+1475.5
NGC5139 (Omega Cen)	13h 26m 45.9s	-47d 28m 36.7s	A	1785.5	115.5	-73.9	-29.4	-83.8
NGC5272 (M3)	13h 42m 11.2s	+28d 22m 31.6s	A	257.9	799.9	-635.0	-303.5	+380.2
NGC5634	14h 29m 37.3s	-05d 58m 35.1s	A	99.5	2073.9	-1643.4	-1256.7	-145.5
NGC5694	14h 39m 36.5s	-26d 32m 18.0s	A	59.8	3450.9	-2390.2	-1998.7	-1483.6
NGC5824	15h 03m 58.5s	-33d 04m 3.9s	A	59.7	3455.8	-2015.1	-2086.2	-1878.8

Table 3: (continued)

Cluster	RA J2000	Dec	Method	FWHM (arcsecs)	Relative Distance	X	Y	Z
NGC5897	15h 17m 24.4s	-21d 00m 36.4s	A	201.5	1023.9	-622.7	-725.3	-366.8
NGC5904 (M5)	15h 18m 33.8s	+02d 04m 57.7s	A	322.6	639.3	-413.7	-486.9	+23.2
NGC5927	15h 28m 0.4s	-50d 40m 22.0s	A	166.3	1240.2	-497.6	-636.9	-940.6
NGC5946	15h 35m 28.6s	-50d 39m 35.0s	A	71.1	2899.1	-1113.8	-1525.7	-2199.3
NGC5986	15h 46m 3.4s	-37d 47m 10.1s	A	173.0	1192.5	-530.8	-802.4	-704.5
NGC6093 (M80)	16h 17m 2.5s	-22d 58m 30.4s	A	158.0	1305.4	-529.2	-1097.6	-468.3
NGC6121 (M4)	16h 23m 35.4s	-26d 31m 31.9s	A	233.5	883.4	-325.7	-727.9	-379.9
NGC6144	16h 27m 14.1s	-26d 01m 29.0s	A	101.8	2026.6	-717.4	-1674.6	-887.6
NGC6139	16h 27m 40.4s	-38d 50m 55.6s	A	98.4	2096.9	-655.2	-1537.6	-1266.4
NGC6171 (M107)	16h 32m 31.9s	-13d 03m 13.1s	A	132.5	1556.8	-565.1	-1408.1	-348.8
NGC6205 (M13)	16h 41m 41.4s	+36d 27m 36.9s	A	384.2	536.9	-144.7	-406.8	+319.1
NGC6218 (M12)	16h 47m 14.5s	-01d 56m 52.1s	A	274.3	751.9	-234.7	-714.4	-0.7
NGC6235	16h 53m 25.4s	-22d 10m 38.8s	A	63.9	3229.4	-858.7	-2872.4	-1200.5
NGC6254 (M10)	16h 57m 9.0s	-04d 05m 57.6s	A	322.3	639.9	-172.9	-614.6	-43.5
NGC6256	16h 59m 32.7s	-37d 07m 17.1s	A	58.1	3553.0	-741.0	-2743.8	-2132.3
NGC6266 (M62)	17h 01m 12.6s	-30d 06m 44.5s	A	306.2	673.7	-148.2	-565.0	-335.7
NGC6273 (M19)	17h 02m 37.7s	-26d 16m 4.6s	A	213.3	966.9	-215.8	-843.9	-419.8
NGC6284	17h 04m 28.8s	-24d 45m 53.3s	A	70.7	2917.7	-643.2	-2602.8	-1151.1
NGC6287	17h 05m 9.3s	-22d 42m 28.8s	A	82.1	2511.4	-554.6	-2273.3	-911.9
NGC6293	17h 10m 10.4s	-26d 34m 54.2s	A	111.0	1858.0	-362.0	-1638.6	-797.5
NGC6304	17h 14m 32.5s	-29d 27m 44.2s	A	96.7	2132.9	-369.2	-1837.0	-1018.9
NGC6316	17h 16m 37.4s	-28d 08m 24.0s	A	76.3	2704.1	-449.8	-2347.9	-1263.6

Table 3: (continued)

Cluster	RA J2000	Dec	Method	FWHM (arcsecs)	Relative Distance	X	Y	Z
NGC6341 (M92)	17h 17m 7.3s	+43d 08m 11.5s	A	270.2	763.4	-103.6	-547.4	+522.0
NGC6325	17h 17m 59.3s	-23d 45m 57.7s	A	39.4	5231.7	-882.8	-4761.6	-1979.6
NGC6333 (M9)	17h 19m 11.8s	-18d 30m 58.5s	A	139.9	1473.8	-249.0	-1383.5	-442.8
NGC6342	17h 21m 10.1s	-19d 35m 14.7s	A	50.8	4063.6	-650.1	-3800.4	-1283.5
NGC6356	17h 23m 35.0s	-17d 48m 46.9s	A	121.0	1705.3	-259.1	-1617.1	-475.4
NGC6355	17h 23m 58.6s	-26d 21m 12.3s	A	63.8	3232.4	-456.1	-2878.0	-1399.0
NGC6352	17h 25m 29.2s	-48d 25m 21.7s	A	108.7	1898.4	-192.1	-1266.2	-1401.4
IC1257	17h 27m 6.0s	-07d 05m 0.0s	A	15.9	12975.1	-1842.7	-12748.2	-1562.5
HP1 (BH229, ESO455-11)	17h 31m 5.2s	-29d 58m 54.0s	A	16.8	12266.0	-1362.5	-10742.3	-5762.0
NGC6362	17h 31m 54.9s	-67d 02m 52.3s	A	197.4	1045.1	-50.0	-406.1	-961.7
NGC6380 (Ton1)	17h 34m 28.0s	-39d 04m 9.0s	A	62.7	3288.6	-284.4	-2542.4	-2066.5
NGC6388	17h 36m 17.1s	-44d 44m 5.8s	A	207.7	993.0	-74.7	-719.2	-680.6
NGC6402(M14)	17h 37m 36.1s	-03d 14m 45.3s	A	248.8	829.1	-80.8	-824.2	-39.8
NGC6401	17h 38m 36.9s	-23d 54m 31.5s	A	103.2	1998.4	-172.5	-1843.6	-751.6
NGC6397	17h 40m 41.4s	-53d 40m 25.3s	A	206.3	999.7	-51.4	-608.8	-791.3
NGC6426	17h 44m 54.7s	+03d 10m 12.5s	A	55.7	3701.1	-243.1	-3687.5	+204.7
NGC6440	17h 48m 52.7s	-20d 21m 34.5s	A	87.2	2366.2	-108.1	-2225.9	-795.3
NGC6453	17h 50m 51.8s	-34d 35m 55.1s	A	105.3	1958.5	-65.2	-1633.8	-1078.2
NGC6496	17h 59m 2.0s	-44d 15m 54.5s	A	113.7	1813.4	-5.5	-1310.3	-1253.7
NGC6517	18h 01m 50.6s	-08d 57m 31.6s	A	74.7	2760.4	+22.0	-2739.5	-338.4
NGC6522	18h 03m 34.1s	-30d 02m 2.3s	A	99.5	2073.1	+28.0	-1795.7	-1035.5
NGC6535	18h 03m 50.7s	+00d 17m 48.9s	A	32.1	6435.1	+108.0	-6434.1	+33.3

Table 3: (continued)

Cluster	RA J2000	Dec	Method	FWHM (arcsecs)	Relative Distance	X	Y	Z
NGC6528	18h 04m 49.6s	-30d 03m 20.8s	A	29.1	7096.9	+129.5	-6148.2	-3542.5
NGC6539	18h 04m 49.7s	-07d 35m 9.1s	A	88.8	2323.7	+48.7	-2308.6	-259.6
NGC6544	18h 07m 20.6s	-24d 59m 50.4s	A	118.9	1734.3	+51.1	-1595.5	-677.7
NGC6541	18h 08m 2.2s	-43d 42m 19.7s	A	226.2	912.0	+23.7	-674.2	-613.7
NGC6553	18h 09m 15.7s	-25d 54m 27.9s	A	158.4	1302.4	+48.0	-1187.9	-531.6
NGC6558	18h 10m 18.4s	-31d 45m 48.6s	A	60.2	3424.3	+133.0	-2955.4	-1724.4
IC1276 (Pal7)	18h 10m 44.3s	-07d 12m 27.3s	A	83.6	2468.6	+114.8	-2448.6	-292.0
NGC6569	18h 13m 38.9s	-31d 49m 35.2s	A	90.1	2290.3	+117.8	-1976.5	-1151.2
NGC6584	18h 18m 37.6s	-52d 12m 54.6s	A	82.7	2492.7	+125.2	-1537.0	-1958.5
NGC6624	18h 23m 40.7s	-30d 21m 38.8s	A	104.7	1970.2	+176.6	-1703.3	-974.4
NGC6626 (M28)	18h 24m 32.9s	-24d 52m 11.4s	A	177.4	1162.5	+114.3	-1062.9	-456.7
NGC6638	18h 30m 56.2s	-25d 29m 47.1s	A	77.3	2667.3	+326.6	-2405.0	-1106.3
NGC6637 (M69)	18h 31m 23.2s	-32d 20m 52.7s	A	118.8	1736.6	+201.8	-1464.5	-911.3
NGC6642	18h 31m 54.2s	-23d 28m 34.1s	A	58.0	3554.3	+455.6	-3251.4	-1361.5
NGC6652	18h 35m 45.8s	-32d 59m 25.1s	A	69.8	2953.6	+393.4	-2500.8	-1521.7
NGC6656 (M22)	18h 36m 24.2s	-23d 54m 12.2s	A	496.5	415.4	+60.9	-380.1	-156.3
NGC6681 (M70)	18h 43m 12.6s	-32d 17m 30.8s	A	98.3	2097.8	+334.5	-1753.0	-1102.6
NGC6712	18h 53m 4.3s	-08d 42m 21.5s	A	155.4	1327.4	+302.2	-1281.5	-168.5
NGC6715 (M54)	18h 55m 3.3s	-30d 28m 42.6s	A	124.0	1663.9	+344.5	-1406.3	-819.9
NGC6723	18h 59m 33.1s	-36d 37m 53.3s	A	150.9	1366.5	+286.3	-1076.9	-791.0
NGC6752	19h 10m 51.8s	-59d 58m 54.7s	A	623.4	330.9	+53.3	-166.9	-280.7
NGC6760	19h 11m 12.1s	+01d 01m 49.7s	A	116.5	1770.4	+541.1	-1685.3	+31.8

Table 3: (continued)

Cluster	RA J2000	Dec	Method	FWHM (arcsecs)	Relative Distance	X	Y	Z
NGC6779 (M56)	19h 16m 35.5s	+30d 11m 4.2s	A	121.4	1698.8	+481.7	-1387.2	+854.1
NGC6809 (M55)	19h 39m 59.4s	-30d 57m 43.5s	A	357.5	576.9	+213.1	-457.1	-280.0
NGC6838 (M71)	19h 53m 46.1s	+18d 46m 42.3s	A	121.8	1692.9	+763.4	-1409.3	+545.0
NGC6864 (M75)	20h 06m 4.8s	-21d 55m 16.2s	A	87.2	2364.6	+1161.1	-1893.2	-811.8
NGC6934	20h 34m 11.5s	+07d 24m 14.9s	A	86.9	2373.7	+1466.9	-1841.0	+305.9
NGC6981 (M72)	20h 53m 27.9s	-12d 32m 13.4s	A	99.8	2067.2	+1391.2	-1472.8	-410.8
NGC7006	21h 01m 29.4s	+16d 11m 14.4s	A	46.9	4398.0	+3005.9	-2967.1	+1226.1
NGC7078 (M15)	21h 29m 58.4s	+12d 10m 0.6s	A	342.7	601.8	+466.7	-358.2	+126.8
NGC7089 (M2)	21h 33m 29.3s	+00d 49m 23.2s	A	271.6	759.5	+609.5	-453.1	+10.9
NGC7099 (M30)	21h 40m 22.0s	-23d 10m 44.6s	A	142.8	1444.9	+1092.1	-762.1	-560.4
Rup106 (C1253-509)	12h 38m 40.2s	-51d 09m 1.0s	M	75.0	2750.2	-1711.7	-291.6	-2132.8
NGC5286	13h 46m 26.6s	-51d 22m 24.5s	M	110.0	1875.1	-1063.5	-532.8	-1449.5
NGC5466	14h 05m 27.4s	+28d 32m 4.2s	M	170.0	1213.3	-910.2	-554.8	+579.6
IC4499	15h 00m 18.6s	-82d 12m 49.6s	M	76.4	2699.8	-272.4	-273.1	-2672.1
NGC6101	16h 25m 48.6s	-72d 12m 5.6s	M	89.0	2318.9	-289.4	-664.0	-2202.9
NGC6229	16h 46m 58.9s	+47d 31m 40.1s	M	100.0	2062.7	-436.3	-1322.7	+1521.4
NGC6366	17h 27m 44.3s	-05d 04m 35.9s	M	175.9	1172.6	-163.9	-1156.7	-100.6
NGC6441	17h 50m 12.8s	-37d 03m 3.9s	M	150.0	1375.1	-46.9	-1097.9	-826.6
NGC6717 (Pal9)	18h 55m 6.2s	-22d 42m 2.8s	M	50.0	4125.3	+915.2	-3733.0	-1498.5
NGC7492	23h 08m 26.7s	-15d 36m 41.3s	M	86.9	2373.7	+2241.3	-512.9	-589.9

Table 3: Milky Way Globular Cluster Data.

Table 4: Unmeasured Globular Clusters.

Cluster	RA (J2000)	Dec	Comment
Pal1	03h 33m 23.0s	79d 34m 49.7s	No distinct object.
Eridanus (C0422-213)	04h 24m 44.5s	-21d 11m 13.0s	Indistinct object with foreground stars obscuring.
Pyxis	09h 07m 57.8s	-37d 13m 17.0s	No visible object at coordinates.
E3 (ESO37-1)	09h 20m 59.3s	-77d 16m 57.0s	Sparse object with no clear boundary.
Pal3	10h 05m 31.3s	00d 04m 16.6s	Indistinct object in noisy background.
Pal4	11h 29m 16.8s	28d 58m 25.1s	Irregular object in noisy background.
NGC4372	12h 25m 45.4s	-72d 39m 32.7s	Sparse object with no clear boundary.
AM4 (C1353-269)	13h 56m 21.2s	-27d 10m 4.0s	No visible object at coordinates.
Pal5	15h 16m 5.3s	00d 06m 41.0s	No visible object at coordinates.
BH176 (ESO224-8)	15h 39m 7.3s	-50d 03m 2.0s	Indistinct object in busy starfield.
Lynga7 (ESO178-11)	16h 11m 3.0s	-55d 18m 52.0s	Indistinct object in noisy background.
Pal14 (AvdB)	16h 11m 4.9s	14d 57m 29.0s	No visible object at coordinates.
Terzan3	16h 28m 40.1s	-35d 21m 13.0s	Sparse object with no clear boundary.
1636-283 (ESO452-SC11)	16h 39m 16.2s	-28d 29m 21.7s	Indistinct object in noisy background.
Pal15	17h 00m 2.4s	00d 32m 31.0s	No visible object at coordinates.
Terzan2 (HP3)	17h 27m 33.2s	-30d 48m 7.8s	Indistinct object.
Terzan4 (HP4)	17h 30m 38.9s	-31d 35m 44.0s	No visible object at coordinates.
Liller1	17h 33m 24.5s	-33d 23m 20.0s	No visible object at coordinates.
Terzan1 (HP2)	17h 35m 47.8s	-30d 28m 11.0s	Indistinct object.
Pal6	17h 43m 42.2s	-26d 13m 21.0s	Indistinct object.
Djorg1 (CL Djorg 1)	17h 47m 28.3s	-33d 03m 56.0s	Indistinct object in noisy background.
Terzan5 (Terzan11)	17h 48m 5.0s	-24d 46m 48.0s	Indistinct object.
Terzan6 (HP5)	17h 50m 46.4s	-31d 16m 31.0s	No visible object at coordinates.
UKS1 (C1751-241)	17h 54m 27.2s	-24d 08m 43.0s	Indistinct object in noisy background.

Table 4: (continued)

Cluster	RA (J2000)	Dec	Comment
Terzan9	18h 01m 38.8s	-26d 50m 23.0s	Indistinct object.
Djorg2 (E456-SC38)	18h 01m 49.1s	-27d 49m 33.0s	Indistinct object in noisy background.
Terzan10	18h 02m 57.4s	-26d 04m 0.0s	No visible object at coordinates.
NGC6540 (Djorg3)	18h 06m 8.6s	-27d 45m 55.0s	Indistinct object in noisy background.
Terzan12	18h 12m 15.8s	-22d 44m 31.0s	No visible object at coordinates.
Pal8	18h 41m 29.9s	-19d 49m 33.0s	Indistinct object.
NGC6749 (Be42)	19h 05m 15.3s	01d 54m 3.0s	Indistinct object.
Terzan7	19h 17m 43.7s	-34d 39m 27.0s	Indistinct object.
Pal10	19h 18m 2.1s	18d 34m 18.0s	Indistinct object.
Arp2	19h 28m 44.1s	-30d 21m 14.0s	Indistinct object.
Terzan8	19h 41m 45.0s	-34d 00m 1.0s	Sparse object with no clear boundary.
Pal11	19h 45m 14.4s	-8d 00m 26.0s	Sparse object with no clear boundary.
Ton2 (Pismis26)	20h 40m 0.4s	-27d 17m 20.8s	No visible object at coordinates.
Pal12	21h 46m 38.8s	-21d 15m 3.0s	Sparse object with no clear boundary.
Pal13	23h 06m 44.5s	12d 46m 19.2s	Indistinct object.

Table 4: Unmeasured Globular Clusters.

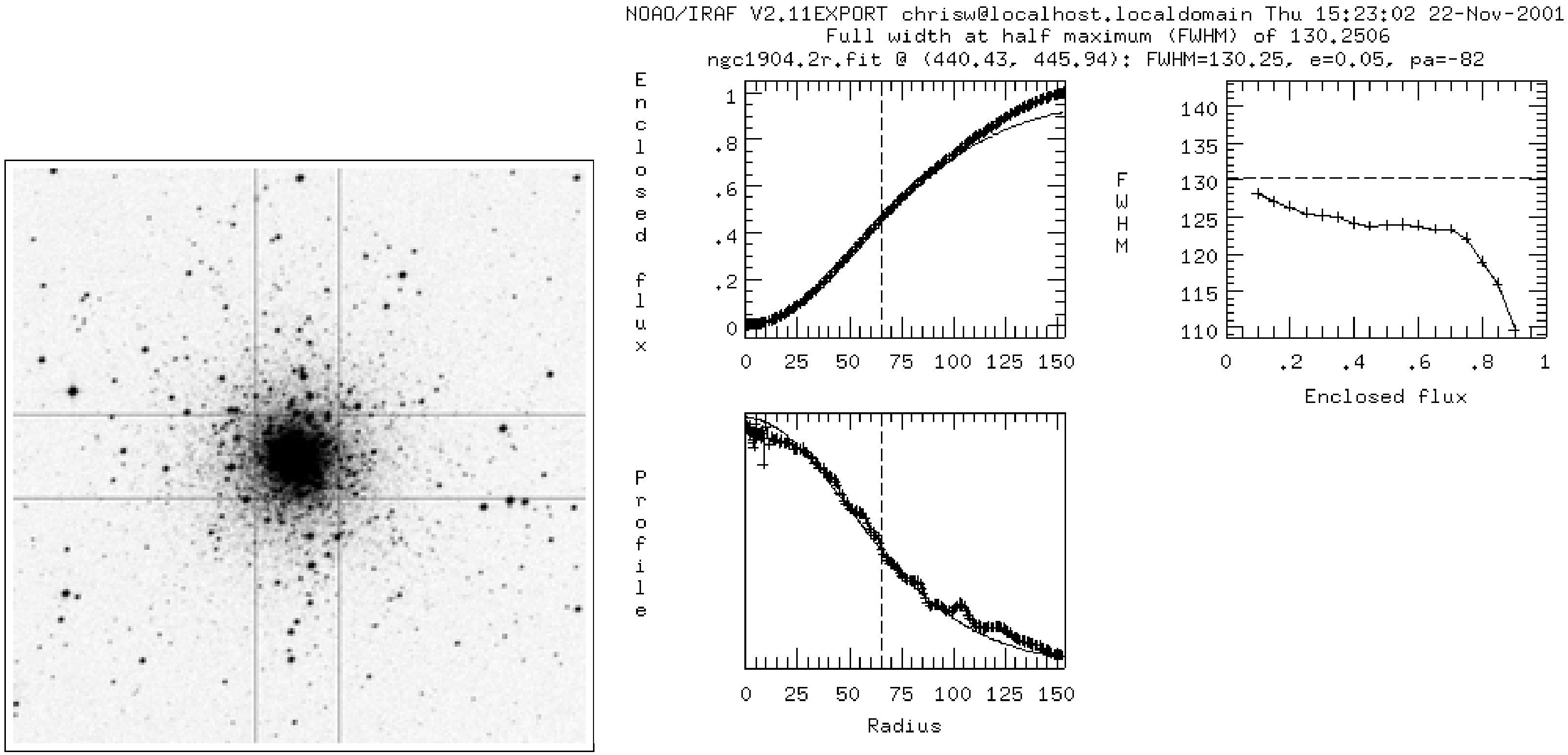

Figure 4: NGC 1904 and its IRAF *psfmeasure* determination of the FWHM. The horizontal and vertical lines in the image show the approximate size of the FWHM.