Chapter V

Review Papers

Globular Clusters

as Tracers

and HST

https://doi.org/10.1017/S0074180900042637 Published online by Cambridge University Press

Martha Hazen and Morton Roberts in discussion

The crowd awaits the opening remarks

INTERSTELLAR MATTER IN GLOBULAR CLUSTERS

Morton S. Roberts

National Radio Astronomy Observatory

"Is there any point to which you would wish to draw my attention?"
"To the curious incident of the dog in the night-time."
"The dog did nothing in the night-time."
"That was the curious incident," remarked Sherlock Holmes.

Memoirs of Sherlock Holmes

I. INTRODUCTION

The source for intracluster matter is seen in various mass loss processes ongoing within clusters and is supported by the theoretical need for mass loss to explain the morphology of cluster color-magnitude diagrams. A variety of techniques ranging from X-ray to radio wavelengths have been employed to search for such matter but with few exceptions has not been found. The amount of material expected to collect between cleansing passages through the galactic plane has variously been estimated at between $\sim 10^2$ and $\sim 10^3$ $M_\odot$. In contrast, observed upper limits for many clusters are well below these values, often < 1 $M_\odot$. The few detections are at levels of $\lesssim 10^{-2}$ $M_\odot$.

This may not be a dilemma for there are a number of proposed mechanisms which will remove diffuse matter from a cluster. Such proposals invoke various assumptions whose acceptance can, in some instances, be guided by observation. Specifically the range of cluster escape velocities and galactocentric distances must be more fully observed before the conflict between prediction and observation is fully resolved.

2. MASS LOSS - PREDICTED AND OBSERVED

The need for mass loss by evolving low mass stars follows most simply from their mass at turn-off, ~ 0.85 $M_\odot$, and the observed mean mass of (field) white dwarfs of ~ 0.55 $M_\odot$. A similar value derives from

J. E. Grindlay and A. G. Davis Philip (eds.),
The Harlow-Shapley Symposium on Globular Cluster Systems in Galaxies, 411–422.

a detailed modeling of the evolution of Population II stars which requires ~0.2 $M_\odot$ loss prior to the horizontal branch phase as well as an additional ~0.1 $M_\odot$ loss in the asymptotic giant branch phase (see, e.g., Renzini 1979 and references therein). For a population of 10^3 stars past turn-off, we expect ~300 $M_\odot$ of material to be fed into intracluster space; this within a period of a few 10^8 years. More quantitative calculations of the cumulative mass loss between passages through the galactic plane give values of 10^2-10^3 $M_\odot$ (e.g., Roberts 1960; Hills and Klein 1973; Knapp, Rose and Kerr 1973; Taylor and Wood 1975). Intracluster matter of this amount in the form of atomic hydrogen, either neutral or ionized, or in molecular form, is easily detectable.

The presence of at least one planetary nebula and two, possibly three, novae within globular clusters tells us that at least some mass loss is ongoing. A more significant source is indicated by the spectra of red giant stars where Hα emission wings are often seen adjacent to the normal Hα absorption line (Cohen 1976; Mallia and Pagel 1978, Peterson 1981; Gratton 1983; Cacciari and Freeman 1983). The emission appears to the red of the absorption line, as in P Cygni stars, to the blue, and in both locations; the last case is reminiscent of Type III P Cygni stars (Beals 1950). In some instances the Hα emission is seen to vary on a time scale of days (Cacciari and Freeman 1983). Measured with respect to the absorption line, the emission features have velocities that are typically ± 50 km s^{-1} and reach as high as ± 80 km s^{-1}.

Cohen (1976) as well as all of the other observers noted above propose that these Hα features arise from a circumstellar shell due to mass loss from the parent star. She derives a minimum mass loss rate ~2×10^{-9} $M_\odot$ yr^{-1} which in the lifetime of a red giant, ~10^8 yrs, will result in a total loss of 0.2 $M_\odot$. Others, e.g., Mallia and Pagel (1978), derive significantly higher mass loss rates, up to 6×10^{-8} $M_\odot$/yr. The difference is related to the adoption of substantially larger radii for the parent stars; values derived from luminosities and effective temperatures. Clearly this latter, larger value of mass loss cannot be continuous over the entire red giant phase. The variability of the Hα emission and its apparent dependence on luminosity (e.g., Cacciari and Freeman 1983) support this conclusion. The detailed dependence is unknown but a total mass loss of order 0.2 $M_\odot$ appears reasonable.

Peterson (1981) has shown that the NaD and Hα lines in several, but not all, globular cluster giants that she studied at high resolution show a core shift to the blue; 11 km s^{-1} for NaD and 6 km s^{-1} for Hα. Others have also reported a blue core shift for Hα in some giants.

The data on red giants are extensive; about two hundred have been observed with over a third showing Hα emission features. However, the proposal that these features are indicative of a circumstellar shell

https://doi.org/10.1017/S0074180900042637 Published online by Cambridge University Press

produced by mass loss is not universally accepted. Several concerns have been raised (Reimers 1981, Dupree et al. 1984, Jura 1986). These include:

(1) The appearance in some instances of only a blue wing.
(2) The short time scale of Hα variability.
(3) The large range in Hα emission for stars of similar L and T_e.
(4) The (unknown) mechanism of mass loss.

Dupree et al. (1984), using semiempirical atmospheric models, find Hα emission wings arising from static chromospheres. An extended atmosphere model yielding a mass loss much less than $2x10^{-9}$ $M_{\odot}$ yr^{-1} also yields line parameters similar in many respects to those observed. They propose observational tests for this chromospheric model and also note that their models do not rule out massive cool winds or transient events that could give rise to substantial mass loss.

As with variants of P-Cygni type stars and spectral-line variations in Be stars, we find the picture for globular cluster red giants complex. The details are not understood but all three categories of stars do show a signature of mass loss.

A further sign of mass loss is suggested by the different spatial distributions of red giants and horizontal branch stars (Oort and van Herk 1959; Woolf 1964); with the latter appearing more extensive. However, the time available, $\sim 10^8$ years, for the apparent redistribution of mass appears short relative to the expected relaxation time (King 1972).

3. REMOVAL OF INTERSTELLAR MATTER FROM GLOBULAR CLUSTERS

The discrepancy between the predicted amount of intracluster matter and the low upper limits derived from observation has prompted a number of viable explanations. These are separable into two categories: "intrinsic," the cleansing mechanism is internal to and part of the cluster, and extrinsic. A basic requirement for both follows from the steady-state nature of the production of intracluster matter: the removal mechanism must clearly also be so.

Several of the intrinsic models involve cluster winds. Scott and Rose (1975) propose that the wind energy arise from stellar ultraviolet radiation. The authors point out that for massive, concentrated clusters (i.e., large, central escape velocity, V_{esc}) such as NGC 6388, a large, significant amount of gas could accumulate in the center. Observations of such high V_{esc} clusters yield the conflicting result of upper limits of ionized hydrogen below those predicted.

Wind models invoking high gas input velocities are proposed by Burke (1968), Faulkner and Freeman (1977), and VandenBerg and Faulkner (1977). Their calculations are consistent with observations but

https://doi.org/10.1017/S0074180900042637 Published online by Cambridge University Press

require injection velocities $\gtrsim 100$ km s^{-1} for extreme cases. Such velocities are significantly greater than red giant emission features imply but not the (low $\dot{M}$) solar wind velocities. VandenBerg (1978) combines both a UV field and a high initial input velocity.

Other intrinsic suggestions include nova-driven winds (Scott and Durisen 1978), winds driven by flare-stars (Coleman and Worden 1977), condensation into stars (Roberts 1960, Johnson 1975), and accretion processes drawing upon a central gas reservoir (e.g., Faulkner and Coleman 1984).

The only extrinsic mechanism proposed (Frank and Gisler 1976, Lea and De Young 1976) invokes continuous sweeping of clusters by the gaseous medium of the galactic halo. For halo densities of 10^{-3} atoms cm^{-3} and relative velocities of $> 10^2$ km s^{-1} such stripping is effective even for large V_{esc}.

All of the methods proposed are strongly dependent on either the assumptions invoked or on poorly known parameters, a situation clearly stated by many of the authors referenced above. Tests of these proposals are possible (e.g., Frank and Gisler 1976, Faulkner and Freeman 1977) and several are made below. A convincing case for any mechanism remains to be made.

4. THE SEARCH FOR INTERSTELLAR MATTER WITHIN GLOBULAR CLUSTERS

There are over two dozen observational searches for intracluster gas and dust; a bibliographic listing is given in Table 1. These cover neutral hydrogen via 21 cm; ionized hydrogen using Fabry-Perot techniques, slit spectra, narrow-band photometry and radio continuum measurements for free-free transitions; searches for distributed OH and for OH and H_2O masers; searches for infrared radiation and for extended X-ray sources. With few exceptions (see Table III) all yield negative results. Upper limits in some instances are less than a solar mass of neutral or ionized hydrogen, M_{gas}. For M15, Conklin (1986) derives an upper limit of 0.1 $M_\odot$ for neutral hydrogen after a 7-hour integration with the Arecibo telescope. Clusters with $1 \leq M_{gas}/M_\odot < 5$ and $M_{gas}/M_\odot < 1$ are listed in Table II.

Such limits raise the question as to whether the best globular clusters have been observed for testing removal mechanisms. Specifically clusters with high central escape velocities are best suited to retain material if an intrinsic mechanism is the correct explanation while large galactocentric distances as well as high escape velocity would favor retention in the extrinsic case.

Data on central escape velocity and galactocentric distance for close to 150 globular clusters are tabulated by Webbink (1985) and displayed in Figure 1 as open histograms. Also shown are the distributions in these two parameters of those clusters which have upper limits noted in Table II.

Table I.

Bibliography on Observational Searches for Diffuse Matter in Globular Clusters

HI - 21 cm

1. 1959 M. S. Roberts, Nature, 184, 1555.
2. 1964 S. J. Goldstein, Jr., Astrophys. J., 140, 802.
3. 1966 C. Heiles and R. C. Henry, Astrophys. J., 146, 953.
4. 1967 B. J. Robinson, Astrophys. Letts., 1, 21.
5. 1972 F. J. Kerr and G. R. Knapp, Astron. J., 77, 573.
6. 1973 G. R. Knapp, W. K. Rose, and F. J. Kerr, Astrophys. J., 186, 831.
7. 1974 E. K. Conklin and R. A. Kimble, Bull. Amer. Astron. Soc., 6, 468.
8. 1975 E. K. Conklin, private communication in 1986.
9. 1979 P. F. Bowers, et al., Astrophys. J., 233, 553.
10. 1983 M. Birkinshaw, P. T. P. Ho, and B. Baud, Astron. Astrophys., 125, 271.

HII - Hα

11. 1976 M. G. Smith, J. E. Hesser, and S. J. Shawl, Astrophys. J., 206, 66.
12. 1977 D. J. Faulkner and K. C. Freeman, Astrophys. J., 211, 77.
13. 1977 J. E. Grindlay and W. Liller, Astrophys. J. (Letters), 216, L105.
14. 1977 J. E. Hesser and S. J. Shawl, Astrophys. J. (Letters), 217, L143.

HII - Radio continuum radiation (free-free)

15. 1973 J. G. Hill and M. J. Klein, Astrophys. Letts., 13, 65.
16. 1975 J. W. Erkes and A. G. Davis Philips, Astrophys. J., 197, 533.
17. 1976 M. J. Klein, Astrophys. Letts., 18, 25.

Molecules (and masers): CO, OH, H_2O - radio

18. 1973 G. R. Knapp and F. J. Kerr, Astron. J., 78, 458.
19. 1978 T. H. Troland, J. E. Hesser, and C. Heiles, Astrophys. J., 219, 873.
20. 1978 M. H. Schneps, et al., Astrophys. J., 225, 808.
21. 1979 N. L. Cohen and M. A. Malkan, Astron. J., 84, 74.
22. 1980 J. M. Dickey and M. A. Malkan, Astron. J., 85, 145.
    Also see No. 9 above.

Infra-red observations

23. 1973 A. D. MacGregor, J. P. Phillips, and M. J. Selby, M.N.R.A.S., 164, 31P.
24. 1975 O. L. Hansen and J. E. Hesser, Nature, 257, 568.
25. 1984 F. C. Gillett, et al., Bull. Amer. Ast. Soc., 16, 526.
26. 1984 F. C. Gillett, et al., Bull. Amer. Ast. Soc., 16, 948.

Extended X-ray

27. 1982 F.D.A. Hartwick, A. P. Cowley, and J. E. Grindlay, Astrophys. J. (Letters), 254, L11.
28. 1985 J. E. Grindlay in Dynamics of Star Clusters, ed. J. Goodman and P. Hut, p. 43.

Dust (references after 1958)

29. 1959 G. M. Idlis and G. M. Nikol'skii, Soviet Astron. (AJ), 3, 652 (1960).
30. 1959 H. S. Hogg, Astron. J., 64, 425.
31. 1960 P. A. Hodge, Publ. Ast. Soc. Pac., 72, 308.
32. 1960 M. S. Roberts, Astron. J., 65, 457.
33. 1978 S. P. Kanagy and S. P. Wyatt, Astron. J., 83, 779.
34. 1981 P. G. Martin and S. J. Shawl, Astrophys. J., 251, 108.

https://doi.org/10.1017/S0074180900042637 Published online by Cambridge University Press

Table II.

Clusters with Low Upper Limits of Interstellar Gas

(a) Ionized Hydrogen from Slit and Fabry-Perot Spectroscopy

$1 \leq M_{HII} \leq 5$		$M_{HII} < 1$	
NGC 104	47 Tuc	NGC 1851	
NGC 362		NGC 5824	
NGC 2808		NGC 5904	M5
NGC 3201		NGC 6093	M80
NGC 4147		NGC 6388	
NGC 5286		NGC 6397	
NGC 5694		NGC 6441	
NGC 5927		NGC 6522	
NGC 6121	M4	NGC 6541	
NGC 6218	M12	NGC 6624	
NGC 6266	M62	NGC 6681	M70
NGC 6333	M9	NGC 6864	M75
NGC 6715	M54	NGC 7078	M15
NGC 6752		NGC 7089	M9
		NGC 7099	M30

(b) Neutral Atomic Hydrogen from 21-cm Spectroscopy

$1 \leq M_{HI} \leq 5$		$M_{HI} < 1$	
NGC 6341	M92	NGC 5272	M3
NGC 6712		NGC 5904	M5
NGC 6809	M55	NGC 6121	M4
		NGC 6205	M13
		NGC 6656	M22
		NGC 7078	M15

See Table I for references. HI data use Webbink (1985) distances.
Units: Solar masses.

https://doi.org/10.1017/S0074180900042637 Published online by Cambridge University Press

Table III.

Reported Detections of Diffuse Matter in Globular Clusters

GAS			
1.	NGC 1851 NGC 5286 NGC 5824 NGC 6266 NGC 6441 NGC 6624 NGC 7078	 M62 M15	Hα detection via narrow band photometry. Inferred mass of ionized hydrogen ~0.02 $M_{\odot}$. Ref.: Table I, No. 13.
2.	NGC 104 NGC 5139 NGC 6656	47 Tuc ω Cen M22	Extended X-ray emission. Ref.: Table I, No. 27, 28.
DUST			
1.	NGC 5272 NGC 6205 NGC 7078	M3 M13 M15	Multicolor photometry of dark regions Avg. cloud ~0.003 $M_{\odot}$. Ref.: Table I, No. 33.
2.	NGC 7078	M15	Tentative detection of polarization in dark region 0.22% ± 0.06%. Ref.: Table I, No. 34.
3.	NGC 104	47 Tuc	IRAS observations. Extended emission at 12, 25, 60 μ · ~ 10^{-6} $M_{\odot}$ dust in central region. Ref.: Table I, No. 25.

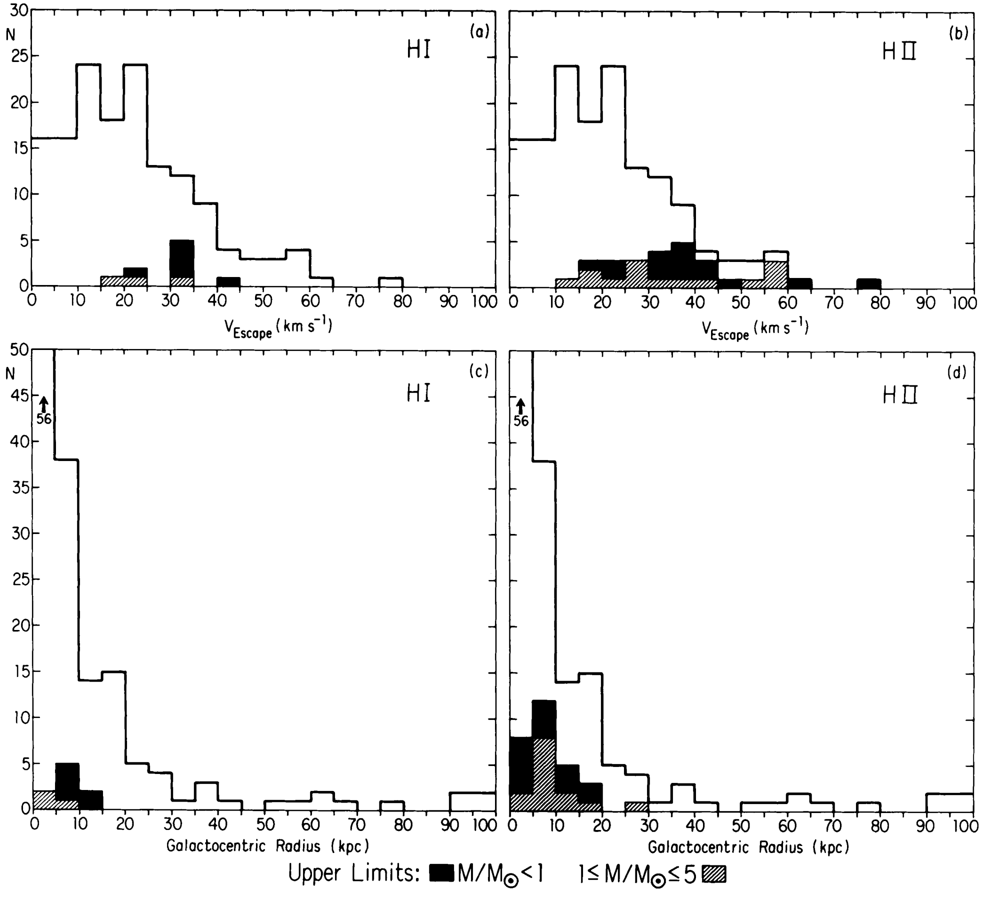

Fig. 1. Open histograms display the distribution of central escape velocities, V_{esc}, and galactocentric distances for globular clusters as tabulated by Webbink (1985). Panel (a) shows as shaded boxes those clusters with low upper limits of neutral hydrogen, HI, while Panel (b) is for ionized hydrogen, HII. Panels (c) and (d) repeat these data as function of galactocentric radius.

https://doi.org/10.1017/S0074180900042637 Published online by Cambridge University Press

Except for HII measurements which do cover the highest V_{esc} values known, the observational data for both HI and HII poorly sample V_{esc} and galactocentric radius. Measurements of extreme cases of these parameters are needed and would effectively limit the various models proposed. Other tests are possible, e.g., measurement of the ultraviolet flux of those clusters with particularly stringent upper limits; further X-ray measurements, etc.

The latter example is particularly important in light of the extended X-ray sources reported by Hartwick et al. (1982) for 47 Tuc, ωCen and M22. A possible interpretation has the X-rays originating from a bow shock in the interaction between a diffuse intracluster medium and the hot gaseous galactic halo (Grindlay 1985).

Dark regions, presumably dust concentrations, are seen towards a number of globular clusters (Idlis and Nikolski 1959, Hogg 1959, Roberts 1960). A drawing of M13 by the Earl of Rosse (1861) based on observations with his 6-foot telescope shows one of the best such examples, a feature confirmed many times over by photographic studies. Monte Carlo simulations (Roberts 1960) and an approximate inverse wavelength dependence of the extinction within these features (Kanagy and Wyatt 1978) rule out as an explanation the chance arrangement of stars within these clusters. One such dark region in M15 shows possible polarization, 0.22% ± 0.06% (Martin and Shawl 1981). Whether the obscuring matter is in or foreground to the cluster is less certain. Either case is interesting.

5. CONCLUSIONS

The low limits, often $< 1 M_{\odot}$, on the diffuse matter within globular clusters require an efficient, steady-state cleansing mechanism for removal. Several mechanisms have been proposed. The existence of extended X-ray sources in the three clusters studied for such sources favors sweeping by the hot gaseous galactic halo. Observations of clusters at large galactocentric distances and with large escape velocities will aid in testing this and other proposed mechanisms. The explanation for the (mostly) missing diffuse matter in globular clusters will open new understanding to the evolution of these clusters.

I am particularly pleased to acknowledge aid in the preparation of this review from W. P. Bidelman, J. E. Bregman, E. K. Conklin, P. S. Conti, D. E. Hogg, I. R. King, and R. T. Rood. The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

REFERENCES

Beals, C. S. 1950 Publ. Dominion Astrophys. Ob. **9**, 1.
Burke, J. N. 1968 Monthly Notices Roy. Astron. Soc. **140**, 241.
Cacciari, C. and Freeman, K. C. 1983 Astrophys. J. **268**, 185.
Cohen, J. C. 1976 Astrophys. J. **203**, L127.
Coleman, G. D. and Worder, S. P. 1977 Astrophys. J. **218**, 792.
Conklin, E. K. 1986 private communication.
Dupree, A. K., Harman, L. and Avrett, E. H. 1984 Astrophys. J. Letters **281**, L37.
Faulkner, D. J. and Freeman, K. C. 1977 Astrophys. J. **211**, 77.
Faulkner, D. J. and Coleman, C. S. 1984 Monthly Notices Roy. Astron. Soc. **206**, 121.
Frank, J. and Gisler, G. 1976 Monthly Notices Roy. Astron. Soc. **176**, 633.
Gratton, R. G. 1983 Astrophys. J. **264**, 223.
Grindlay, J. E. 1985 in IAU Symposium No. 113, Dynamics of Star Clusters J. Goodman and P. Hut, eds., D. Reidel, Dordrecht, p. 43.
Hartwick, F. D. A., Cowley, A. P. and Grindlay, J. E. 1982 Astrophys. J. Letters **254**, L11.
Hills, J. G. and Klein, M. J. 1973 Astrophys. Letters **13**, L65.
Hogg, H. S. 1959 Astron. J. **64**, 425.
Idlis, G. M. and Nikol'skii 1960 Soviet Astron. J. **3**, 652.
Johnson, H. M. 1975 Astrophys. J. **202**, 490.
Jura, M. 1986 Astrophys. J. **301**, 624.
Kanagy,S. P. and Wyatt, S. P. 1978 Astron. J. **83**, 779.
King, I. R. 1972 in Evolution of Population II Stars A. G. D. Philip, ed., Dudley Obs., Albany, p. 31.
Knapp, G. R., Rose, K. W. and Kerr, F. J. 1973 Astrophys. J. **186**, 831.
Lea, S. M. and De Young, D. S. 1976 Astrophys. J. **210**, 647.
Mallia, E. A. and Pagel, B. E. J. 1978 Monthly Notices Roy. Astron. Soc. **184**, 55P.
Martin, P. G. and Shawl, S. J. 1982 Astrophys. J. **251**, 108.
Oort, J. H. and van Herk, G. 1959 Bull. Astron. Inst. Netherland **14**, 299.
Peterson, R. C. 1981 Astrophys. J. Letters **248**, L31.
Reimers, D. 1981 in Physical Processes in Red Giants I. Iben, Jr. and A. Renzini, eds., D. Reidel, Dordrecht, p. 269.
Renzini, A. 1979 in Stars And Star Systems B. E. Westerlund, ed., D. Reidel, Dordrecht, p. 155.
Roberts, M. S. 1960 Astron. J. **65**, 457.
Rosse, Earl 1861 Phil. Trans. Roc. Soc. London, 151, plate 28.
Scott, E. H. and Rose, W. K. 1975 Astrophys. J. **197**, 147.
Scott, E. H. and Durisen, R. H. 1978 Astrophys. J. **222**, 612.
Taylor, R. J. and Wood, P. R. 1975 Monthly Notices Roy. Astron. Soc. **171**, 467.
VandenBergh, D. A. 1978 Astrophys. J. **224**, 394.
VandenBergh, D. A. and Faulkner, D. J. 1977 Astrophys. J. **218**, 415.

Webbink, R. F. 1985 in IAU Symposium No. 113, Dynamics of Star Clusters J. Goodman and P. Hut, eds, D. Reidel, Dordrecht, p. 541.
Woolf, N. J. 1964 Astrophys. J. **139**, 1081.

DISCUSSION

GRINDLAY: The possible Hα emission reported in the Grindlay and Liller paper was not claimed as necessarily due to diffuse gas (~$0.02M_o$) but instead perhaps due to individual red giants, as found at about the same time by Cohen. As for the extended X-ray emission, the derived total mass of the hot gas is uncertain because of the uncertain geometry of the emitting X-ray shell (cf. discussion in my paper in the IAU 113 Proceedings).

ROBERTS: Because of the obvious uncertainty in the mass estimate from the X-ray data I do not quote the value given in IAU 113 Proceedings in my table of detections.

VAN DEN BERGH: 2 or 3 novae have been discovered in globular clusters indicating a nova rate of ~ 2 per century. Since globular clusters contain ~ 1% of the halo population this suggests a rate of ~ 200 galactic halo novae per century. Do you think this is reasonable or might the nova frequency in globular clusters be unusually high?

ROBERTS: It does appear high but the globular cluster numbers are so few that I hesitate to draw a meaningful comparison.

GNEDIN: In my opinion there are two sensitive methods for a search for hot gas: 1. The change of the position of radio sources behind a cluster due to refraction. 2. The change of the polarization plane due to the Faraday effect. Both effects are noticeable especially in the decameter radio range of the spectrum.

KING: Continuous sweeping by halo gas is more attractive than sweeping by the Galactic plane. If a cluster has to wait for passages through the plane, the gas is likely to condense centrally to a density where it will be retained.

SCHOMMER: Lake and Schommer looked at HI in low luminosity ellipticals several years ago. They also looked at two dwarf spheroidals (Leo I & II). They detected no HI, although failed to publish that result. As I recall the upper limits are $<50\ M_\odot$, but someone should harass me if they wish the actual numbers. Some earlier searches did not look at the correct velocity range, I believe.

ROBERTS: The sequence of globular clusters, dwarf spheroidals and elliptical galaxies, all of which have essentially negative results (except for a few apparently special case ellipticals) must have an important clue on the cleansing mechanism(s).

RENZINI: A straightforward calculation shows that when clusters were ~ 10^8 yrs old, the rate of mass return from stars was ~1000 times higher

https://doi.org/10.1017/S0074180900042637 Published online by Cambridge University Press

than it is today. The cooling rate in the gas was then about one million times higher, and the conditions were much more favorable for retaining gas in clusters. This may have left some observable consequences (e.f. composition anomalies??).

MATHIEU: Since Bob has begun confessing of unpublished data, Leo Blitz and I searched several of the "dust" lanes in several clusters for CO emission. We found no emission to sensitive limits. You presented a reference to a similar study. Could you say something more about that study; what limit did they place on the presence of H_2?

ROBERTS: Troland, Hesser and Heiles in Ap. J. **219**, 873, 1978 looked for CO in some of the more prominent dust lanes. They found only upper limits but did not estimate an upper limit to the H_2.

COHEN: Can EXOSAT confirm the rather tentative detection by Einstein of extended X-ray emission around 3 globular clusters?

ROBERTS: Somebody said that EXOSAT is not sensitive enough.

CUDWORTH: The proper motion of M 22 is in the wrong direction for the extended X-ray source to be a bow shock. In this line of sight, however, the association of the source with the cluster must be rather uncertain.

ROBERTS: Hartwick et al. (Ap. J. 254, L11, 1982) note that the proper motion for ω Cen is appropriate for a bow shock explanation.

ADUR: Your data seem to be interesting but I remember a similar search was carried out by Faulkner et al. (1977) where his estimates were lower than the ones you have mentioned. Could you take the same value, or do you intend to give any upper limits for the values.

ROBERTS: I took Faulkner, et al. data. They are listed under the category $< 1M_\odot$ for H II.