COMMENT ON THE STANDARD OF REST ASSOCIATED WITH THE NEUTRAL RING AT THE CENTRE OF THE GALAXY

S.V.M. Clube
Department of Astrophysics
University of Oxford, U.K.

ABSTRACT. The evidence for a large systemic motion of the neutral ring at the centre of the Galaxy is reviewed, indicating that the local standard of rest is probably receding from the centre at around 40 kms^{-1}.

1. THE CIRCUMNUCLEAR RING

The circumnuclear ring (R ~ 2-8 pc) of dust and neutral gas inclined at ~ 20^0 to the plane is now a well recognised feature of the Galaxy's central region. Though clumpy, the ring is essentially complete with a relatively coherent velocity field: it is also unusually warm and dense with an excitation and gas pressure that both fall off rapidly with increasing R. The main large scale motion of the ring is rotation about the centre at ~ 110 kms^{-1} but its internal and systemic radial motions are not so clear. Thus, on the one hand, the ring is seen as having axial symmetry and a systemic radial motion of ~ 40 kms^{-1} (Gatley et al 1986, Kaifu et al 1987, Clube 1986) whilst on the other, although axial symmetry is not exactly set aside, a systemic value of 0 kms^{-1} is assumed and very considerable large scale deviations from symmetry are permitted. (Lugten et al 1986, Serabyn et al 1986, cf Genzel & Townes 1987). In particular, if the value of 0 kms^{-1} is assumed, equal and opposite tangential velocities are no longer equidistant from the centre, whilst the velocity of the ring's prominent and seemingly integral NW arc is not even approximately circular. The possibility of significant internal radial motions in the circumnuclear ring cannot be excluded since the NW arc in particular connects rather smoothly with the emission from more highly ionized sources closer to the nucleus (R $\leqslant$ 2 pc) where the velocities become much larger and demonstrably non-circular.

The ~ 40 kms^{-1} difference is not easily resolved however since it is correlated with a known ambiguity in the LSR; thus the standards of rest relating to well mixed galactic orbits and spiral arms may be the same locally (ellipsoidal hypothesis) or they may differ by ~ 40 kms^{-1} (two stream hypothesis) (Clube 1983b). On the former hypothesis, it is customary to treat spiral arms as relatively minor perturbations of the

M. Morris (ed.), The Center of the Galaxy, 473–476.

galactic gaseous disc due to density waves, whereas on the latter hypothesis, it seems they may be massive injections of dark matter from the nuclear region (Clube 1988). Thus it is not known with certainty whether star formation proceeds from the gravitational collapse of gas clouds or by the aggregation of pre-formed sub-stellar bodies from which the observed clouds dissipate during condensation (McCrea 1978). In view of these ambiguities therefore, both at the galactic centre and in the solar neighbourhood, the preferred value of the circumnuclear ring's systemic velocity is rather surprisingly dependent at this time on the presumed nature of star formation (Clube 1988).

2. THE 40 KMS^{-1} CLOUD

Molecular clouds with highly non-circular motions are not uncommon in the galactic centre region. Two such clouds approximately 8 pc either side of the nucleus, one to the Galactic WSW and the other more or less E, which are seen in absorption at ~ 20 kms^{-1} and ~ 50 kms^{-1} and are part of a general band of cold gas close to the galactic plane with a central line-of-sight motion of ~ 40 kms^{-1}, are apparently illuminated by Sgr A West beyond. This suggests large scale infall on the nearside of the nuclear region. On the other hand, a considerable part of the ~ ~ 50 kms^{-1} cloud may be beyond the centre and largely illuminated by Sgr A East (Gusten et al 1981), consistent with a central systemic line-of-sight motion of ~ 35-40 kms^{-1} and a very strong velocity gradient across Sgr A West suggestive of systemic differential rotation and/or radial motion. The magnitude of the gradient is in fact prima facie evidence in favour of the second alternative since the cloud positions and implied angular momenta may well indicate some degree of continuity with the circumnuclear ring.

H_2CO 40 kms^{-1} absorption in the same general region (Whiteoak et al 1974) is strongest in positions coincident with the conspicuous absorbing band ~ 5-10 pc to the galactic S of Sgr A* (Glass et al 1987, Gatley et al 1988) but is also definitely present in front of the latter (Sandqvist & Bernes 1980). Optically thin submillimetre emission at 540 μm (Hildebrand et al 1978) and HCN emission (Fukui et al 1977) are strongest however in a parallel overlapping band which is roughly coextensive with the circumnuclear ring. A similar though weak feature is also observed in HI at ~ 40 kms^{-1} (eg Liszt et al 1983, Figure 2b) which is not obviously connected with the ~ 40-60 kms^{-1} bridge between Sgr A West and Sgr A East. Elsewhere, in the ~ 20 kms^{-1} cloud for example, 540 μm emission and H_2CO are well correlated (Gusten & Downes 1980), indicating the possible presence of H_2CO in the circumnuclear ring beyond and to the galactic N of Sgr A*, which is not seen in absorption for lack of significant background illumination. The overall impression therefore is of H_2CO concentrating towards the perimeter of the circumnuclear ring, where most of the 2 μm continuum absorption is located, but observed only on the nearside moving with the systemic line-of-sight motion of ~ 40 kms^{-1}. Notwithstanding the

paucity of HI towards the centre of the ring, there is also a clear trend of HI velocity across the ring from galactic S to N of -10 to +90 kms^{-1} (see Schwarz et al 1977, Figure 1c), consistent with a general expansion $\leq$ 50 kms^{-1} as well as its mean velocity of 40 kms^{-1}.

Lines of sight through the centre of the ring are evidently not devoid of neutral gas from the ring and high resolution spectra of the infrared sources within it (Geballe et al 1988) provide another means of determining the ring's systematic motion. In particular IRS 1 and 2 (which are clumps of gas and dust in the ionized flow immediately surrounding the nucleus) are seen to be beyond clouds belonging to the ring's nearside with velocitites in the range ~ 0-40 kms^{-1}, whilst IRS 3 and 7 (which are protostellar and young stellar objects respectively) are, in addition, within or beyond clouds belonging to the ring's farside with velocities in the range ~ 40-80 kms^{-1} (Clube & Waddington 1988). These two bands of velocity are identical to those observed in neighbouring sections of the neutral ring's eastern and western arcs respectively, implying again that the inclined ring is viewed from above (relative to the CNP and GNP) and that the line-of-sight velocities of these arcs are symmetrically disposed about a central velocity of ~ 40 kms^{-1}. Warmer gas from the inner core of the circumnuclear ring moreover is viewed in the ~ 20-60 kms^{-1} core of the R5 profile of the ^{12}CO 1-0 line at 4.6412 μm, also implying a central velocity of 40 kms^{-1}.

According to these inferences, therefore, the "40 kms^{-1}" cloud mostly comprises a cold, outer extension (8 $\leq$ R $\leq$ 20 pc) of the expanding circumnuclear ring (2 $\leq$ R $\leq$ 8 pc; $\Pi \leq$ 50 kms^{-1}), which is itself expanding only slowly, if at all, and which is seen against the centrally concentrated continuum emission from Sgr A West and thus predominantly on the nearside. The kinematic continuity extends also to the emission from hotter, more ionized gas and dust interior to the circumnuclear ring, as judged for example by their similar velocities in the NW arc: however, the kinematically discordant, highly ionized 'bar' within R ~ 1 pc does not at present allow the innermost velocity field to be easily resolved.

3. CONCLUSION

There is now a variety of indicators in the central region of the Galaxy that there exists an even larger circumnuclear ring than heretofore supposed, reaching out to at least 20 pc from the nucleus and characterized by both a systemic motion of ~ 40 kms^{-1} and a current maximum outflow velocity of ~ 50 kms^{-1}. Such a result indicates that the local standard of rest is receding from the galactic centre at ~ 40 kms^{-1} but the ring's evolution from a more compact configuration within 10^5 yr seems then very likely as well. The implication overall is that the Galaxy's large scale spiral system is also rapidly expanding and when coupled with the increasing evidence of strong outward motion in the Galaxy's globular cluster system (Clube & Waddington 1989),

https://doi.org/10.1017/S0074180900186929 Published online by Cambridge University Press

indicates that the Galaxy may rather frequently experience extreme gravitational action in the centre of a kind (cf Clube 1983a) not hitherto generally perceived.

4. ACKNOWLEDGEMENTS

This paper has benefitted from helpful comments by Dr Mark Morris and a referee, which are gratefully acknowledged.

REFERENCES

Clube S.V.M. 1983a Liege Coll. 24, 393
Clube S.V.M. 1983b ESA SP - 201, 173
Clube S.V.M. 1986 Observatory 106, 166
Clube S.V.M. 1988 In Dust in the Universe (ed. M.E. Bailey & D.A. Williams), 327
Clube S.V.M. & Waddington W.G. 1988 Mon.Not.R.astr.Soc. in press
Clube S.V.M. & Waddington W.G. 1989 in preparation
Fukui Y. et al 1977 Publ.Astron.Soc.Japan 29, 643
Gatley I. et al 1986 Mon.Not.R.astr.Soc. 222, 299
Gatley I. et al These proceedings
Geballe T.R. et al 1988 Astron.Astrophys, in press
Genzel R. & Townes C.H. 1987 Ann.Rev.Astron.Astrophys. 25, 377
Glass I.R. et al 1987 Mon.Not.R.astr.Soc. 227, 373
Gusten R. & Downes D. 1980 Astron.Astrophys 87, 6
Gusten R. et al 1981 Astron.Astrophys. 103, 197
Hildebrand R.H. et al 1978 Astrophys.J. 219, L101
Kaifu N. et al 1987 A.I.P. Conf. Proc No 155, "The Galactic Centre" (ed D.C. Backer), 106
Liszt H.S. et al 1983 Astron.Astrophys. 126, 341
Lugten J.B. et al 1986 Astrophys.J. 306, 691
McCrea W.H. 1978 In Origin of the Solar System (ed. S.F. Dermott), 75
Sandqvist A. & Bernes C. 1980 IAU Symp 87, 103
Schwarz U.J. et al 1977 Astron.Astrophys. 54, 863
Serabyn E. et al 1986 Astron.Astrophys. 169, 85
Whiteoak J.B. et al 1974 Astron.Astrophys. 36, 245.