Planetary Nebulae near M31: Vestigial Tracers of a Collision with M33?

Bruce Balick, Department of Astronomy, University of Washington, Seattle, WA 98195-1580, balick@uw.edu
Romano L. M. Corradi, Instituto de Astrofisica de Canarias, E-38200 La Laguna, Tenerife, Spain, rcorradi@iac.es
Karen B. Kwitter, Department of Astronomy, Williams College, Williamstown, MA 01267; kkwitter@williams.edu
Richard B. C. Henry, H.L. Dodge Dept. of Physics and Astronomy, U. Oklahoma, Norman, OK 73019, USA; rhenry@ou.edu

Spectroscopic data of two bright PNe, M174 and M2496, that lie a degree from the center of M31 and along its minor axis (Fig. 1) have been obtained at the 10.4-m Gran Telescopio Canarias. We find that these and 16 other outer PNe between 20 < galactocentric distance R_g < 45 kpc studied by us earlier (Kwitter et al 2012) form a homogeneous group in metal content (approximately solar, Fig. 2), progenitor mass (1.5–2.2 $M_\odot$), age (≈2 GY), and kinematics. The kinematics of the set of 18 PNe are very similar to those of the disk but unlike those of M31's halo or stellar streams. Using M31's disk rotation curve, M174 and M2496 lie at galactocentric distances R_g of 55 and 57 kpc, far beyond the HI warp (R_g ≈ 30 kpc).

Beyond the warp no HII regions are found (Azimlu et al 2011), no IR emission from dust is visible (Monalto et al. 2009), and HI is all but undetectable (Corbelli et al 2010). Furthermore the ensemble of PNe is too young and metal-rich to have formed at the same time as M31's old, metal-poor outer disk or halo.

The fundamental science question is simple:
How did the homogeneous group of young, massive, metal-rich PNe at such large galactocentric distances form?

These unusually metal-rich PNe at large R_g are not alone. A survey of Ca II lines in luminous red giants near most of the PNe by Chapman et al. (2006) has uncovered four fields of RGBs with exceptionally metal-rich stars (0.5 < [Fe/H] ≤ 1; Fig. 3, blue arrows). (The ages of the RGBs are not measured.)

The rich history of star formation outside of the HI warp of M31's disk has received much attention recently. We have considered and rejected the possibility that the set of PNe migrated to their locations from the metal-rich ISM of M31's inner disk in the past 2 GY. Also, the assimilation of metal-poor dwarf galaxies is not a tenable explanation.

One very attractive hypothesis is that the PNe formed in a starburst in metal-rich ISM ejected by an M31-M33 encounter about 3 GY in the past (McConnachie et al. 2009). Circumstantial evidence of such an event was reported by Bernard et al (2012) based on deep stellar C-M diagrams in two fields, one just beyond the HI warp and the other at the outer edge of M33's disk. *The collision of M31 and M33 putatively stripped metal-rich ISM from the disks of both galaxies and triggered a burst of star formation from the detritus shortly thereafter (Fig. 4). The group of PNe are evolved products of the starburst.*

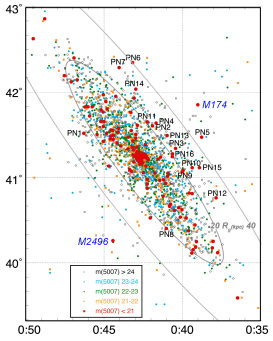

Fig. 1. The locations of the PNe observed with the GTC, M174 and M2496, are shown (blue font) along with 16 outer PNe similarly studied by KL+12 (black font). The inner ellipses represent the tilted disk at R_g = 20 (40) kpc.

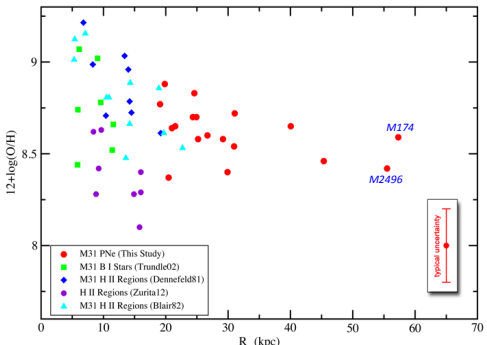

Fig. 2. Values of O/H plotted against deprojected or "rectified" galactocentric distance R_g for various nebulae in M31. The red dots are all eighteen targets of this and our previous paper, KL+12. The average value of 12+log(O/H) for the eighteen PNe is 8.41 ± 0.14. We have adopted D = 770 kpc (Freeman & Madore 1990) and a disk inclination = 77.5°.

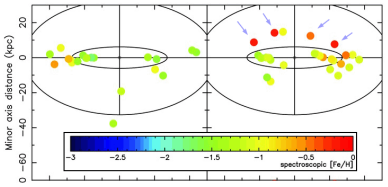

Fig. 3. [Fe/H] measurements derived from the stacked Keck/DEIMOS spectra of at least ten high-S/N stars per field adapted from Chapman et al (2006, Fig. 9). The stars in each field were kinematically separated into halo (left graphs) and disk populations (right graphs). The top panels show the corresponding spatial distribution and average metal content of the observed fields. The inner ellipse shows the projected disk at a radius of R_g = 20 kpc. The blue arrows in the right panel show the disk fields close to most of the PNe in our sample.

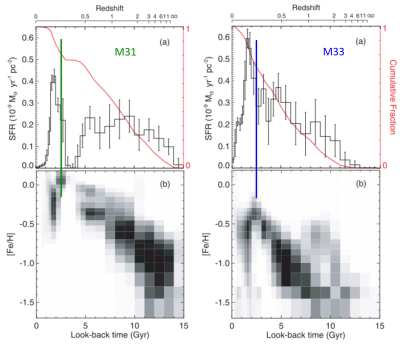

Fig. 4. Star-formation history and stellar metal content derived from the CMDs of two HST/ACS fields at the outer edges of the disks of M31 and M33 (assembled from various figures in Bernard et al 2012).

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References

Azimlu, M., Marciniak, R., & Barmby, P. 2011AJ....142..139A
Bernard, E. J., Ferguson, A. M. N., Barker, .M. K. et al. 2012MNRAS.420.2625B
Chapman, S. C., Ibata, R., Lewis, G. F. et al. 2006ApJ...653..255C
Corbelli, E., Lorenzoni, S., Walterbos, R. et al. 2010A&A...511A..89C
Freedman, W. L. & Madore, B. F. 1990ApJ...365..186F
Kwitter, K. B., Lehman, E. M. M., Balick, B., & Henry, R. B. C. 2012ApJ...753...12K
McConnachie, A. W., Irwin, M. J., Ibata, R. A. et al. 2009Natur.461...66M
Montalto, M., Seitz, S., Riffeser, A. et al. 2009A&A...507..283M