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ANDROMEDA VIII: A NEW TIDALLY DISTORTED SATELLITE OF M31

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ABSTRACT

We report the detection of a new satellite of M31, projected close to M32. Andromeda VIII is tidally distorted, with length ∼10 kpc and width a few kiloparsecs. It contains 5–12 planetary nebulae and 1–3 globular clusters and has a velocity of -204 km s^{-1} with respect to M31, some 350 km s^{-1} away from M32's velocity. There are also $\sim 4 \times 10^5$ $M_\odot$ of H I, well-separated from the disk, at the same position and velocity. The satellite has luminosity of 1.2–2.4 $\times 10^8$ $L_\odot$ and a central surface brightness of the order of $\mu_V = 24$. Both these values are typical of Local Group dwarf galaxies. Its surface brightness is some 6 mag brighter than any of the stellar streams found in the Milky Way or M31. The three associated globular clusters have reddening consistent with foreground reddening from the Milky Way only, making it likely that the satellite is in front of M31, unlike the giant tidal stream of Ibata et al., which is behind M31 in the southeast quadrant. However, the major axis of And VIII is aligned with the western edge of this giant stream, and we suggest that its unusual fan shape is caused by superposition of two streams, the westernmost of which was tidally stripped from And VIII.

Subject headings: galaxies: dwarf — galaxies: evolution — Local Group

On-line material: color figures

1. INTRODUCTION

Tidal streams from disrupting dwarf satellites provide a rich fund of information about both their progenitor satellite and the dark matter halo of the parent galaxy (e.g., Johnston et al. 1999). In the Milky Way, studies of the streams of the Sgr dwarf galaxy (e.g., Ibata, Gilmore, & Irwin 1994; Ibata et al. 2001b; Dohm-Palmer et al. 2001; Majewski et al. 2003) are starting to teach us about both. The detection of tidal streams around M31 (Ibata et al. 2001a; Ferguson et al. 2002; McConnachie et al. 2003) has raised the prospect of similar investigations of the accretion history and mass distribution of the Andromeda galaxy.

Kinematics of stream stars are vital, as they allow us to constrain the orbit of the stream and progenitor. These are more difficult to obtain in M31 than the Milky Way because, at its distance, velocities of individual stream red giants require 10 m class telescopes. However, both planetary nebulae (PNe) and globular clusters are far more luminous, and observations with 4 m class telescopes can easily provide good spectra and velocities.

Unfortunately, both of these tracers are rare: in a survey reaching 2.5 mag down the PN luminosity function (PNLF), only one PN is detected per 3×10^7 $L_\odot$—the estimated luminosity of the *entire* giant stream found in the southeast region of M31 (Ciardullo et al. 1989; Ibata et al. 2001a). Only the two most luminous dwarf spheroidal (dSph) galaxies in the Milky Way have PNe: the Sgr dwarf has two and Fornax one (Zijlstra & Walsh 1996). Only objects with larger luminosity, such as M32, will have significant numbers of PNe associated (Nolthenius & Ford 1986 found 15). We expect any PNe associated with the M31 streams to be from strong density enhancements such as the still-bound cores of accreting satellites. Dwarf spheroidal galaxies of this luminosity also have only a few globular clusters (Mateo 1998).

There are now high-quality velocities available for over 300 globular clusters and 135 PNe in M31. The globular clusters have velocity errors of 12 km s^{-1} (Perrett et al. 2002), and the PNe, observed in a new survey that reaches out to 20 kpc from the center, have even more accurate velocities with typical errors of 5 km s^{-1} (Hurley-Keller et al. 2003). Such velocity precision allows, for the first time, sensitive searches both for disk kinematics (Morrison et al. 2003) and for velocity substructure. In this Letter, we report on a group of PNe and globular clusters close to the projected position of M32 that have a very low velocity dispersion and a mean velocity that differs by 350 km s^{-1} from M32's. There are also two small H I clouds at similar position and velocity. We suggest that they belong to a previously undiscovered satellite of M31's, with luminosity of the order of 10^8 $L_\odot$, which is currently undergoing tidal disruption.

2. PN, CLUSTER, AND H I KINEMATICS

To search for substructure in regions projected on the disk, we need to recognize the disk's kinematical signature. This is particularly clear when narrow strips parallel to the major axis are plotted with velocity versus X (distance along the major axis: Brinks & Shane 1984; Morrison et al. 2003). In Figure 1, we show the kinematics of PNe and globular clusters in a strip with Y (distance parallel to the minor axis) from -4 to -7 kpc. These Y-distances deproject to distances of 18–31 kpc (3–6 disk scale lengths) from the major axis. Thin-disk objects show a diagonal line in this diagram because much of their circular velocity is projected away from the line of sight. This region is shown shaded in the figure.

While more than half of the PNe in this region have disk

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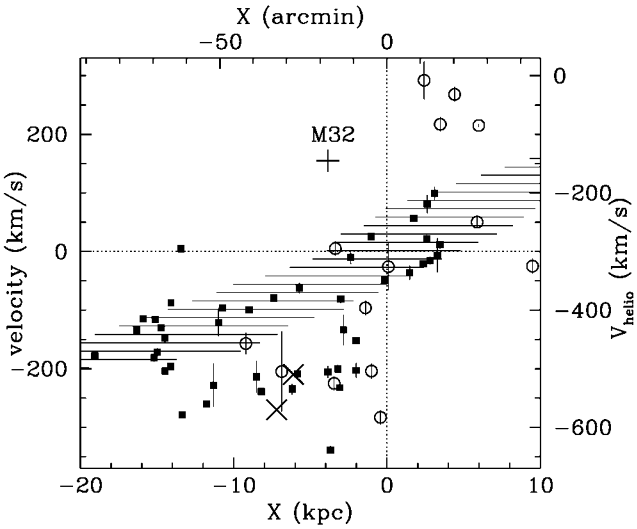

FIG. 1.—Kinematics of PNe and globular clusters in a strip parallel to the major axis with $Y = -4$ to -7 kpc. Velocities are with respect to M31 and are plotted against distance along the major axis. The shaded region shows the expected range of velocity of disk objects, from 100 simulations of disk kinematics as described in Morrison et al. (2003). PNe are plotted as black filled squares, globular clusters as open circles, and H I detections as crosses. While more than half of the PNe in this region show velocities typical of disk objects, there is a narrow velocity feature stretching over almost 10 kpc with mean velocity -204 km s^{-1} that contains 5–12 PNe and 1–3 globular clusters. Although M32 is located close to this region on the sky, its velocity is ∼350 km s^{-1} away. [*See the electronic edition of the Journal for a color version of this figure.*]

kinematics, we also see a narrow velocity feature stretching over almost 10 kpc with mean velocity ~-200 km s^{-1} with respect to M31 (-500 km s^{-1} heliocentric). It contains 5–12 PNe and 1–3 globular clusters. Although M32 is located close to this position on the sky, its velocity is ∼350 km s^{-1} away. There is also some evidence that the feature extends out to $X = 14$ kpc, showing a velocity gradient. However, we restrict our discussion here to the five PNe whose velocities are, within their individual 1 σ errors, identical to -204 km s^{-1}, and the three globular clusters whose velocities agree with this velocity within their 2 σ errors.

Figure 2 shows the location of the objects in this velocity feature. It can be seen that they trace out a very elongated structure about 10 × 2 kpc in size. In Tables 1 and 2 we give velocities for all possible members of this structure and metallicity and $E(B-V)$ estimates for the globular clusters. Data

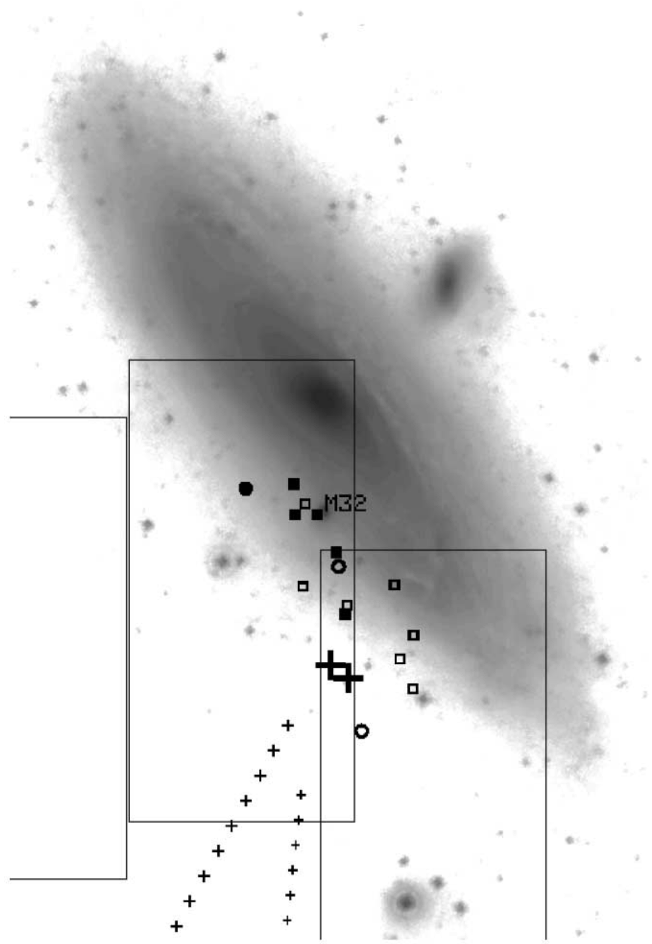

FIG. 2.—Location of objects in the narrow-velocity feature, shown overlaid on an image of M31 taken on the Burrell Schmidt telescope, kindly made available by R. Walterbos. North is up and east is to the left. The limits of our Schmidt survey for the PNe are shown with solid black lines. Circles are globular clusters, squares PNe, and plus signs H I detections. Filled squares and circles are objects that differ by less than 5 km s^{-1} from the mean stream velocity of -204 km s^{-1}, while open squares and circles denote objects with velocity between -200 and -300 km s^{-1}, which may be members of the feature if it has a velocity gradient. The edges of the giant stream of Ibata et al. (2001a) are marked with black plus signs. The stream appears to fan out in its southern regions. The densest part of the stream (its eastern edge) is shown with larger plus signs, while the western edge is shown with the near-vertical line of smaller plus signs. It is intriguing that the western edge is roughly aligned with the body of And VIII. [*See the electronic edition of the Journal for a color version of this figure.*]

TABLE 1
LIKELY PN MEMBERS OF ANDROMEDA VIII

ID	R. A. (2000.0)	Decl. (2000.0)	X (arcmin)	Y (arcmin)	Velocity (km s^{-1})	Error
HKPN 97	00 43 0.63	40 57 44.5	−2.015	−4.138	−502.8	12
HKPN 94	00 43 15.18	40 51 12.7	−3.202	−4.993	−500.3	6
HKPN 81	00 42 49.84	40 51 10.6	−3.864	−4.149	−505.7	10
HKPN 75	00 42 22.82	40 43 06.6	−5.860	−4.521	−509.1	7
HKPN 71	00 42 04.07	40 29 37.7	−8.515	−6.024	−513.8	27
HKPN 51	00 40 44.02	40 25 08.7	−11.32	−4.032	−528.2	37
HKPN 91	00 43 05.26	40 53 34.1	−3.081	−4.286	−532.3	5
HKPN 87	00 42 56.18	40 35 40.4	−6.188	−6.821	−534.8	9
HKPN 70	00 42 03.33	40 31 39.8	−8.207	−5.677	−539.0	4
HKPN 62	00 41 12.34	40 35 58.2	−8.840	−3.281	−528.4	10
HKPN 57	00 40 56.88	40 20 00.9	−11.79	−5.253	−560.5	4
HKPN 49	00 40 37.96	40 13 35.5	−13.35	−5.645	−578.9	3

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

TABLE 2
Likely Globular Cluster Members of And VIII

ID	X (arcmin)	Y (arcmin)	Velocity (km s^{-1})	Error	[Fe/H]	Error	$E(B-V)$	Error
B219-S271 ……	−4.65	−25.40	−504	12	−0.73	0.53	0.13	0.03
B176-S227 ……	−15.84	−23.49	−525	12	−1.60	0.10	0.04	0.04
B85-S147 …….	−31.52	−18.44	−505	68	−1.83	0.40	0.15	0.07

are from Hurley-Keller et al. (2003) for the PNe and from Perrett et al. (2002) and Barmby et al. (2000) for the globular clusters. We use the naming convention of Barmby et al. (2000) for the globular clusters.

The H I survey of Brinks & Shane (1984) shows two small H I features well isolated from the disk H I, at similar position and velocity: they are shown in Figures 1 and 2. The mass of H I associated with each feature is of the order of $2 \times 10^5\ M_\odot$. These H I detections have been confirmed by a new survey of M31 in H I (Braun et al. 2003)[4] that reaches to much lower column density: Thilker et al. (2003) find a giant H I tail extending tens of kiloparsecs away from the M31 disk to the southeast, most apparent at a heliocentric velocity of −500 km s^{-1}.

3. DISCUSSION

It is remarkable to find such a tight velocity feature in not only PNe and globular clusters but also in H I. Because of the short evolutionary time of PNe, this feature has a substantial stellar luminosity, which we calculate below.

It is clear from Figure 1 that it is not associated with M31's thin disk. Although M31 is known to have a substantial disk warp, the closeness to the minor axis means that any warp stars would also have most of their velocity perpendicular to the line of sight. The probability of five PNe with such low-velocity dispersion being drawn from a smooth dynamically hot population such as the bulge is very small.[5] The heliocentric velocity of the feature (−504 km s^{-1}) also makes any association with the Milky Way halo unlikely. We conclude that the feature is either a tidal stream or a hitherto undiscovered satellite of M31's, whose projection close to M31 has made it invisible until velocity data were available.

What is its luminosity? We use the number of PNe per unit luminosity of Ciardullo et al. (1989) and the limiting magnitude of our survey in this area (2.5 mag down the PNLF; Hurley-Keller et al. 2003) and find a corresponding total luminosity of $1.5 \times 10^8\ L_\odot$ and an absolute magnitude of $M_V = -15.6$. (We obtain a similar luminosity by scaling by the number of PNe detected in M32 in our survey.) This is a factor of 5 ± 2 times the total luminosity of the giant star stream in the regions detected by Ibata et al. (2001a), who estimate a luminosity of $3 \times 10^7\ L_\odot$, an absolute magnitude of $M_V = -14$, and an average surface brightness of $\mu_V = 30$ mag arcsec^{-2} for the regions of the giant stream that they can detect in their star counts.

The surface brightness associated with this feature is $\mu_V \sim 23.8$ mag arcsec^{-2}, assuming that its central four PNe are contained in a region of 12 kpc^2. This is typical for Local Group dwarf galaxies, which have central surface brightness values ranging from $\mu_V = 22.1$ to 26.5 mag arcsec^{-2} (Mateo 1998). This estimate of the central surface brightness explains why the feature has not been discovered with imaging surveys. It subtends almost a degree on the sky and has significantly lower surface brightness than the M31 disk in this region. The disk has $\mu_V = 20.9$ at a distance of 7 kpc out on the southeast minor axis, and the surface photometry of Walterbos & Kennicutt (1988; kindly made available by Rene Walterbos) shows that the galaxy surface brightness is roughly constant between the minor axis and $X = -10$ kpc over the region occupied by this feature.

Although the elongated shape of the feature could indicate that we are observing a portion of a star stream rather than a tidally distorted but still-bound satellite, its luminosity places it at the bright end of the existing dSph *satellites* in the Local Group. Its surface brightness is some 6 mag brighter than the giant stream discovered by Ibata et al. (2001a) and the star streams discovered in the Milky Way halo. In addition, it appears to stop abruptly near the minor axis: although we have detected a number of PNe and globular clusters at similar Y-values and positive X, none of these objects has velocities near −500 km s^{-1}. We conclude that this is a still-bound satellite of M31's that is tidally distorted but not completely disrupted, and we christen it And VIII. Its large velocity difference with M32 makes it unlikely that they are physically associated.

The reddening of the globular clusters provides an interesting constraint. All three clusters have low values of $E(B-V)$ (0.13, 0.15, and 0.04, respectively; Barmby et al. 2000), which are consistent with the foreground reddening from the Milky Way [$E(B-V) = 0.08$; Burstein & Heiles 1978]. If the stream were located on the far side of M31, we would expect to see a significantly higher reddening of these globular clusters. Ford, Jacoby, & Jenner (1978) estimate that there are 0.5 mag of reddening due to M31's disk at the position of M32. We examined the globular cluster reddening values classified as "good" for clusters with $|Y| > 4$ kpc from Barmby et al. (2000) and found reddening values ranging from $E(B-V) = 0.04$ to 0.40. Since we would expect the globular clusters to be scattered both in front and behind the galaxy, this suggests that the reddening due to M31's disk is at least as high as $E(B-V) = 0.40$. We conclude that the satellite is likely located on the near side of M31. The outer regions of the giant stellar stream in the southeast quadrant are on the far side of M31 (McConnachie et al. 2003), so it is unlikely that And VIII is part of it. This is also consistent with the fact that it is elongated roughly at right angles to the giant stream. However, it is intriguing to note that the giant stream appears to fan out in its southern portions (see, for example, Fig. 2 of Ferguson et al. 2002). The westernmost boundary of this fan-shaped feature is roughly aligned with the And VIII major axis: further imaging and PN detections in this region of the stream will allow us to test whether it is formed by the disruption of And VIII.

The position of the And VIII HI detections is intriguing because they seem slightly offset from the stellar locus of And VIII. While the survey of Braun et al. (2003) will provide much more accurate positional information for the H I asso-

[4] See http://www.astron.nl/astron/newsletter.

[5] To make a rough estimate of how likely this is, we simulated 10,000 samples of 15 nondisk PNe from a population with velocity dispersion 80 km s^{-1}. Only 0.2% of these samples had five objects within 10 km s^{-1}. The spatial association would make it less likely still.

ciated with And VIII, we note that ram pressure stripping from hot gas in M31's halo might cause the H I to follow a different locus from the stars.

Is there any more substructure of such relatively high surface brightness seen in the regions that we surveyed? In this Letter, we have used the very low velocity dispersion of the PNe and globular clusters plus their spatial clustering to infer that they belong to a separate satellite of M31's. We examined the regions covered by our PN survey (an area bounded roughly by $X = -20$ to $+10$ kpc and $Y = 0$ to -20 kpc) for other substructure and found no strong evidence for other substructure. This constrains the existence of other satellites in the large area covered by our survey.

4. SUMMARY

Using high-precision velocities of both PNe and globular clusters in a region near M32, we have located a feature with very low velocity dispersion (unresolved within our errors) that contains 5–12 PNe, 1–3 globular clusters, and two H I clouds. Its velocity (-204 km s^{-1} with respect to M31) differs from M32's by some 350 km s^{-1}. It is projected on the outer disk of M31, which explains why it has not been detected before.

It shows an elongated shape (size $\sim 10 \times 2$ kpc), covers almost a degree on the sky, and has a total luminosity of $\sim 10^8\ L_\odot$ and a mean surface brightness of $\mu_V \sim 24$ mag arcsec^{-2}. These values are typical of the Local Group dwarf galaxies and some 6 mag brighter than the tidal streams discovered in the Milky Way and M31. We conclude that it is a tidally disrupting dwarf satellite of M31. There are two H I features associated with And VIII that contain of the order of $4 \times 10^5\ M_\odot$, about 0.1% of its total luminous mass. And VIII appears to be a dSph galaxy with a small amount of associated H I.

All three globular clusters have $E(B-V)$ values consistent with foreground reddening from the Milky Way, so it is likely that And VIII, like M32, is in front of M31. The giant stellar stream of Ibata et al. (2001a) is behind M31 in this region, so And VIII, if it is on the same orbit as this stream, must be on a very different part of it. The giant stream displays an unusual fan shape, and the westernmost edge of the fan aligns roughly with the major axis of And VIII. It is possible that this feature is actually two streams superposed on the line of sight, with the westernmost stream tidally stripped from And VIII. Velocity measurements of stream stars will soon be available, allowing us to constrain the orbits of star streams in M31, investigate their connection with And VIII, and use them to study M31's dark halo.

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