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Merger in M31's Bulge & 3-D Accretion – A BVRI CCD Study at Kiso –

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Abstract. By contrast-enhancing and colour-excess analyses of *BVRI* CCD images of the central $12'.5 \times 12'.5$ region of M31 taken with the Kiso 105 cm Schmidt telescope, we found a "face-on" spiral feature of dark clouds, which are associated with Hα spirals. The feature can be understood as being due to accretion of gas clouds from companion galaxies and/or from a merger galaxy in the past 10^{8-9} years.

1. Face-on Spiral Structure of Dark Clouds

CCD images of the central $12'.5$ region in the B, V, R and I-bands have been obtained with the Kiso 1.05/1.50 m Schmidt telescope (Sofue et al. 1994). Fig. 1 shows a colour image indicating the spatial distribution of $B - I$. A conspicuous feature in this image are "face-on spirals" on a scale of a few hundred pc, which comprise dark lanes and clouds. The face-on spiral features coincide with the Hα spiral feature observed by Ciardullo et al. (1988). We stress that the spiral pattern appears to be independent of the major spiral structure of the main disk of M31. The dark clouds recognized in our analysis are not associated with any star-forming regions, as indicated from a careful inspection of the B-band image. The face-on spiral is further connected to a more central mini-bar structure of 100 pc length, which is evident in contrast-enhanced images in B to I bands.

2. Depletion of Gas in the Central Few kpc and the Large Gaseous Ring

Although the peculiar spirals are conspicuous in the colour and contrast-enhanced images, the amount of gas itself is anomalously small: The colour excess of the darkest cloud in the field is estimated to be $E(B-V) \simeq 0.22$, which corresponds to $N(\mathrm{H}+\mathrm{H}_2) \sim 1.2 \times 10^{21}$ atoms cm^{-2}, giving a mass of $\sim 3 \times 10^4 \, M_\odot$ for a cloud size of 50 pc. The total mass of dark clouds in the central 1 kpc region is estimated to be less than $\sim 10^6 \, M_\odot$.

The depletion of gas in the central region can be confirmed by CO and HI observations. We performed ^{12}CO (J = 1-0) line observations of the central few arc minutes region using the Nobeyama 45 m telescope (Sofue & Yoshida 1993). No significant emission was detected in the central 100 pc, yielding an upper limit of the molecular hydrogen mass of $\sim 1 \times 10^5 \, M_\odot$. We detected weak CO

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emission toward the darkest cloud complex 200 pc north of the center. The total mass involved in this dark complex is estimated to be $10^6\, M_\odot$, which is probably the most massive one within the central few hundred pc. This fact as well as the result obtained from the colour excess study indicates a striking contrast to the nuclear disks of "normal" Sb galaxies like our Galaxy and NGC 891, in which the central few-hundred pc region contains molecular gas almost two orders of magnitude more massive. The observations also indicated anomalously small ratios of the CO intensity and colour excess to the virial mass, suggesting a very low metal abundance.

Moreover, M31 is known for its HI ring of 10–12 kpc radius which is associated with a slightly smaller-radius CO ring of radius 9–10 kpc (Roberts & Whitehurst 1975; Dame et al. 1993). In particular, the molecular-ring radius is anomalously large compared to the molecular ring radius (3–5 kpc) observed in Sb galaxies like the Milky Way and NGC 891.

In view of the depletion, or large-radius hole, of interstellar gas as well as of the fact that no indication of star formation can been recognized in the B-band images, the central few kpc of M31 are more characteristic of an early type galaxy of type S0/E.

3. Merger and Evolution of the Disk into S0/E Type

A possible scenario, which could explain the face-on spiral structure of ionized gas in the central few hundred pc, involves ejection of high temperature gas from bulge stars (Ciardullo et al. 1988). However, since the central few kpc contain very little gas, it appears difficult for the gas flow, particularly the molecular gas clouds, to be collimated along such spirals as observed. A starburst origin would also be unlikely, since no indication of star-forming activity is observed.

We propose an alternative scenario to explain the peculiar features based on the ram pressure stripping-and-accretion model of gaseous debris from companion galaxies (Sofue 1994). Fig. 2 shows the result of a simulation, in which gas clouds from a companion (either M32 or NGC 205) are stripped and accreted onto the central region of M31 along accretion spirals. A merger galaxy, which is suggested from the existence of the double nuclei (Lauer et al. 1993), could be an alternative origin of the gaseous debris. In this scenario we assume that the companions and the merger galaxy contained much interstellar gas in the past. During orbiting motions around M31 which is surrounded by a gaseous halo, HI and molecular gas clouds in the companions are stripped off, and finally captured by M31. The captured clouds are then rapidly accreted toward the M31 disk along highly-tilted (polar) spiral orbits within $\sim 10^9$ yr. The clouds, then, make a polar rotating disk in the central region, in which the clouds are further accreted toward the nucleus along spiral orbits in $\sim 10^8$ yr.

Some of the clouds would remain in the form of molecular clouds, which have been observed as dark face-on spirals. The clouds would also be partially ionized due to the friction by the ambient gas, producing the Hα spiral features. If the companion galaxies, including the possible merger galaxy, were of metal-poor galaxies similar to the Magellanic Clouds, the anomalously small ratios of the CO intensity and colour excess to cloud mass can be explained.

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Figure 1. $B-I$ CCD image of the central $12'.5 \times 12'.5$ region of M31. Note the "face-on" spiral pattern comprising dark clouds.

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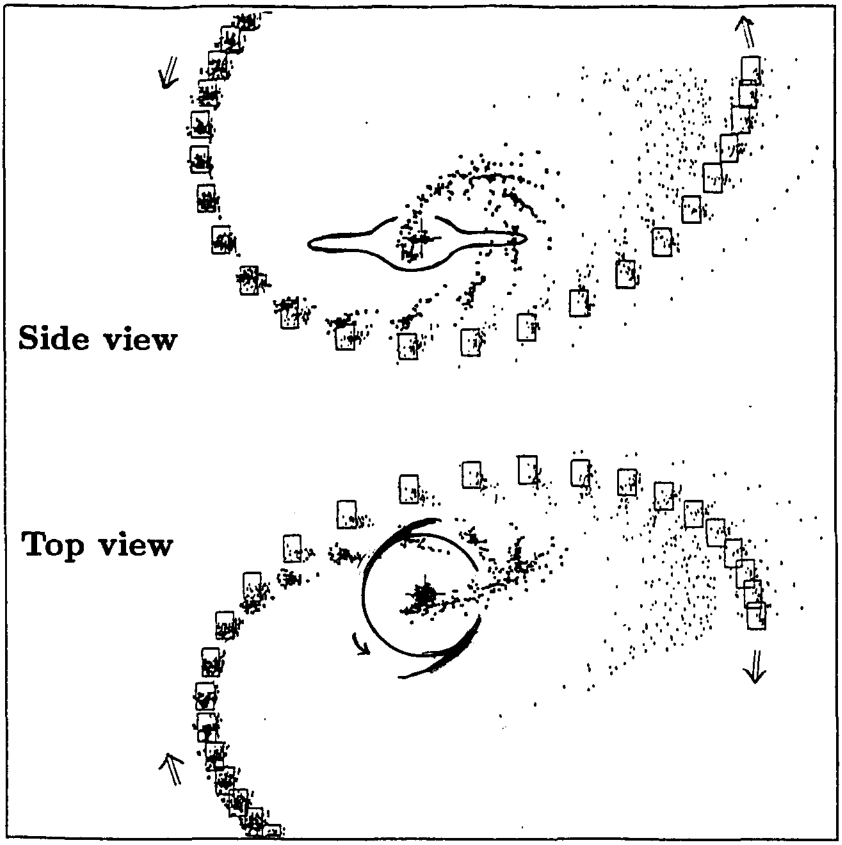

Figure 2. Ram pressure accretion of gaseous debris from a companion galaxy onto the central region of M31. Note that a spiral feature perpendicular to the disk is produced.

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The accretion of massive gas clouds, and possibly the merger of one or more companions, would have caused disruption of the nuclear gas disk. This would have caused the central region to evolve into an early-type galaxy of S0/E type. At the same time, the gravitational disturbance would have caused the central mini-bar structure. Furthermore, a bar-induced accretion of interstellar gas might be somehow related to the formation of the compact massive object suggested to be present in the nucleus.

4. Conclusions

From observational facts, that: (i) The central region of M31 lacks gas and mimics E/S0; (ii) The molecular and ionized gases, although of small amount, form a spiral perpendicular to the main disk; (iii) The nucleus involves a second nucleus, we argue for a possible merger/capture scenario of companions and their gaseous component onto the M31 center in the past. M32 and NGC 205 are thought to be bulge remnants of such gas-stripped satellites, which are now being merged by M31.

We mention that merger of satellite galaxies would not be a unique event in M31, but will be observed in any galaxies, including our own. For example, the Magellanic Clouds, and possibly another satellite(s), would be indeed falling toward the Milky Way.

References

Ciardullo R., Rubin V. C., Jacoby G. H., Ford H. C. & Ford Jr. W. K., 1988, AJ, 95, 438

Dame T. M., Koper E., Israel F. P. & Thaddeus P., 1993, ApJ, 418, 730

Lauer T. R., Faber S. M. et al., 1993, AJ, 106, 1436

Roberts M. S. & Whitehurst R. N., 1975 AJ, 26, 483

Sofue Y., 1994, PASJ, in press

Sofue Y. & Yoshida S., 1993, ApJ, 417, L63

Sofue Y., Yoshida Y., Aoki T., Soyano T., Tarusawa K., Hamabe M. & Wakamatsu K., 1994, PASJ, 46, 1

Discussion

N. Reid: Can one say anything about either the time scale since the last burst of satellite accretion, or the amount of mass accreted, based on the velocity dispersion or thickness of the M31 disk?

Sofue: Yes, since the main (outer) disk of M31 is not severely disturbed, the mass of the victim must have been small compared to the total mass of M31. However, such quantities depend not only on the mass of the victim and epoch of the merger, but also sensitively on its initial orbit (spin and orbital angular momenta before merger). In addition, we need to know the structure of M31 itself before the merger. So, it may be quite difficult to say something definite.

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Isobe: Could the merging companion galaxy survive without disruption by M31 during its gradual approach to the center of M31?

Sofue: The infalling galaxy is strongly disturbed, and the gaseous component is stripped by ram pressure. Only the central bulge of the infalling galaxy can survive. M32 and NGC 205 may be such bulge remnants of larger galaxies. Even such remnants will be disrupted during the final merger to the central region, except for the compact massive object, which indeed appears to have been observed as the second nucleus of M31.

Hydayat: Is it possible to suppose that, not only M31, but also many or all other galaxies are in a similar merging state?

Sofue: Yes. If any galaxy is associated with companions, or is a member of group or cluster, the galaxy inevitably experiences merger due to the dynamical friction, either in the past or in the future, or even at present.

Gilmore: Can you say something about our Galaxy and its companions?

Sofue: Yes. It is known that the Magellanic Clouds are approaching the Galaxy, and their binary nature will be destroyed soon, say in a billion years. The LMC will then be merged by the Galaxy, and later, the SMC. Similarly, a larger number of satellite galaxies might have already fallen onto the Galactic disk. Gilmore's object, which is crossing the galactic plane at 12 kpc from the galactic center, is interesting in this context: it might be a remnant of a galaxy (the third MC) already fallen into the Galaxy.

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