A $5° \times 5°$ deep HI survey of the M81 group

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ABSTRACT

A 25 deg^2 region, including the M81 complex (M81, M82, NGC 3077), NGC 2976 and IC2574, was mapped during ~ 3000 hours with the DRAO synthesis telescope. With a physical resolution of ~ 1 kpc, these observations allow us to probe a large region down to column density levels of $\sim 1 \times 10^{18}$ cm^{-2} over 16 km s^{-1}, mapping the extent of the HI arm connecting the system and NGC 2976, and resolving the HI clouds adjacent to the arm. The observations also reveal a few clouds located between the system and IC 2574, probably tidally stripped from a past interaction between the two systems. Given the regular velocity distribution in the HI envelope of the system, we attempt and derive an idealised large-scale rotation curve of the system. We observe a flat trend for the rotation velocity of the overall system from 20 kpc out to 80 kpc, well beyond the outskirts of the M81 disk, although with asymmetries like a wiggle at the vicinity of M82. This supports the assumption that intergalactic gas and galaxies in the system participate to a large-scale ordered rotation motion which is dominated by M81. Also, our HI analysis of the group further supports the hypothesis that the galaxies forming the system moved closer from afar, in agreement with numerical simulations.

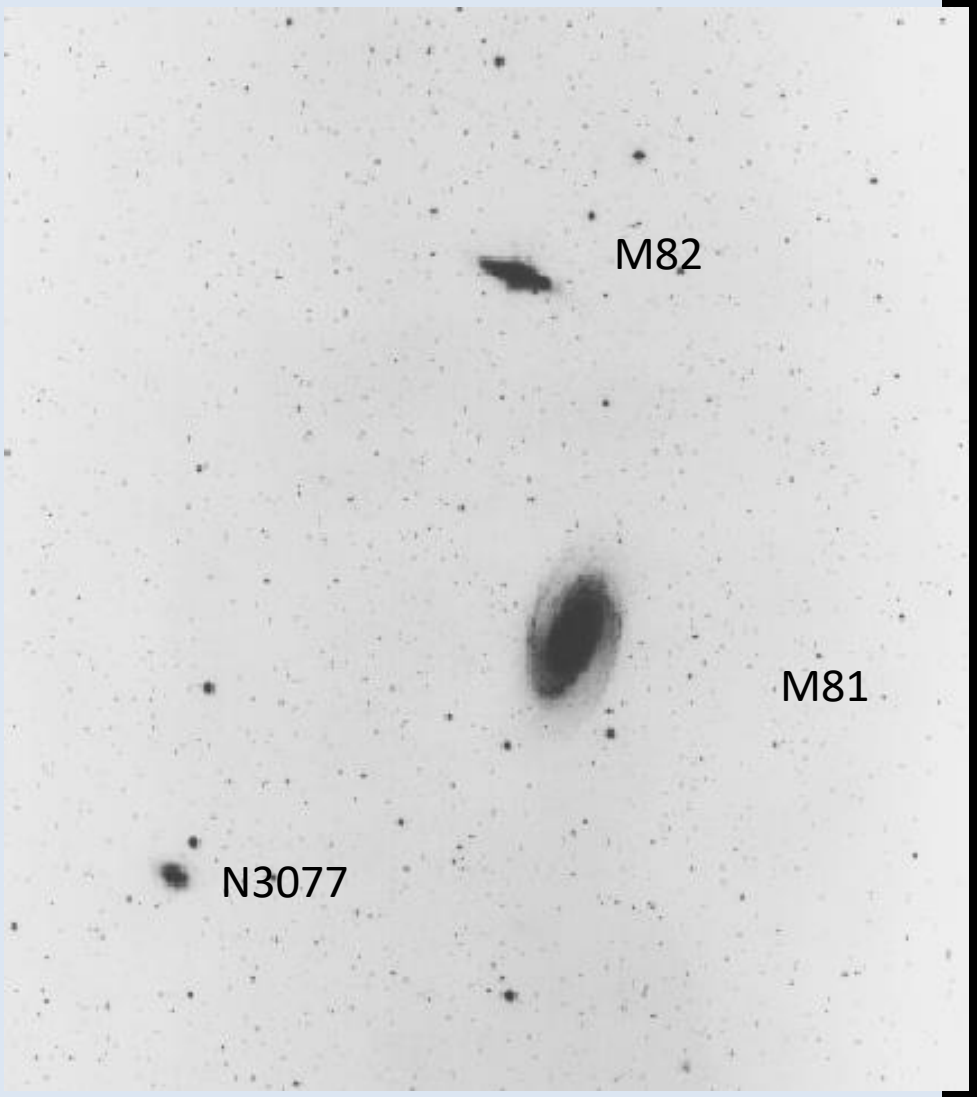
Key words: galaxies: groups; galaxies: evolution; galaxies: interactions; galaxies: kinematics and dynamics; galaxies: ISM; galaxies: individual: M81, M82, NGC 3077, NGC 2976, IC 2574, Ho IX.

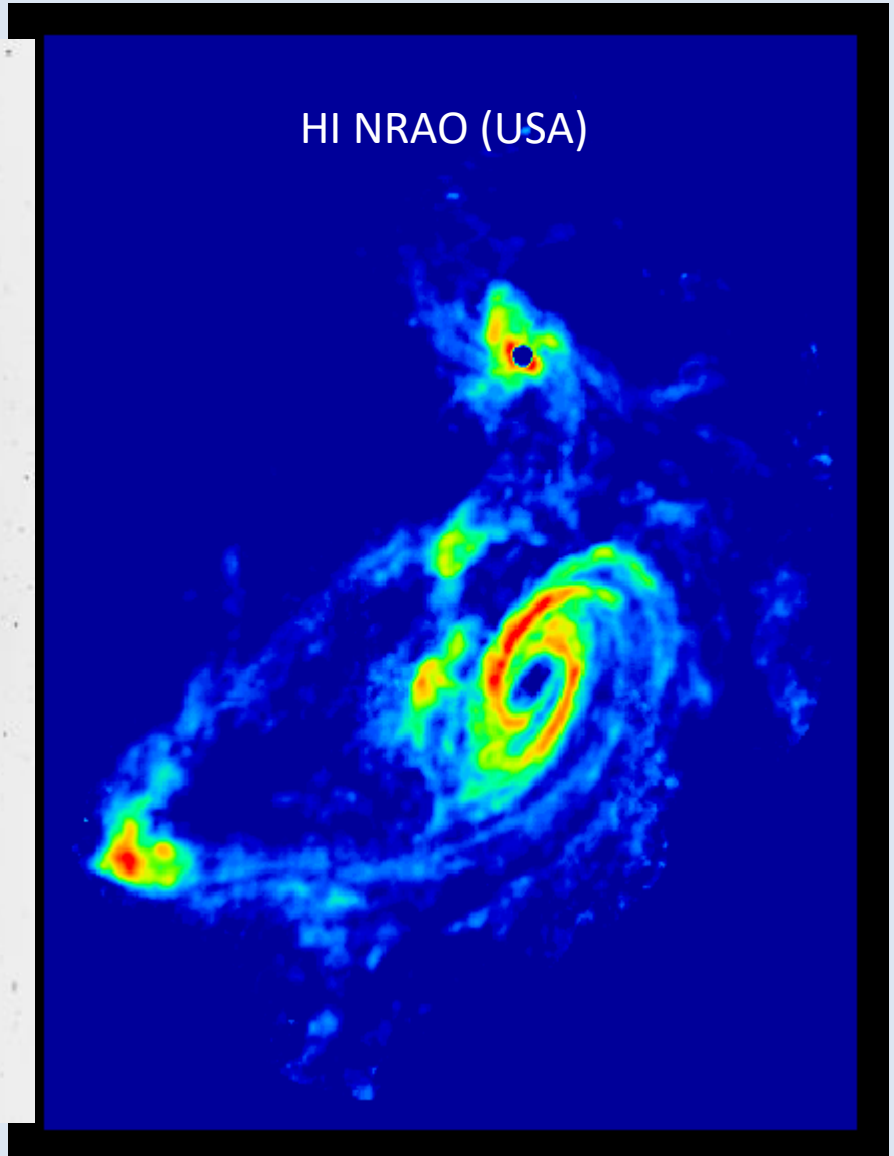
1 INTRODUCTION

Galaxy interactions are a key process driving the evolution of galaxies in the Universe. The theory predicts that the morphology and gas content of galaxies are shaped by the interactions with their environment and counterparts (e.g., Toomre & Toomre 1972; Gunn & Gott 1972; Dressler 1980). In particular, tidal interactions are known to affect the stellar disk and star formation rates of galaxies (e.g., Cayatte

arguably the M81 group, whose main galaxy members (M81, M82 and NGC 3077) seem to share a common HI envelope although their optical disks are distinct.

The M81 group has been the subject of many HI observational studies over the last two decades. However, most of these studies either focused on individual galaxies in the group at high angular resolution (e.g. THINGS; Walter et al. 2008), or covered a large field of view but lacked angular resolution (e.g. GBT observations, Chynoweth et al. 2008,


M82
M81
N3077


HI NRAO (USA)

M81 активно взаимодействует с двумя галактиками: M82 и NGC3077.Чуть поодаль – еще две gas-rich галактики: NGC2970 и IC2574

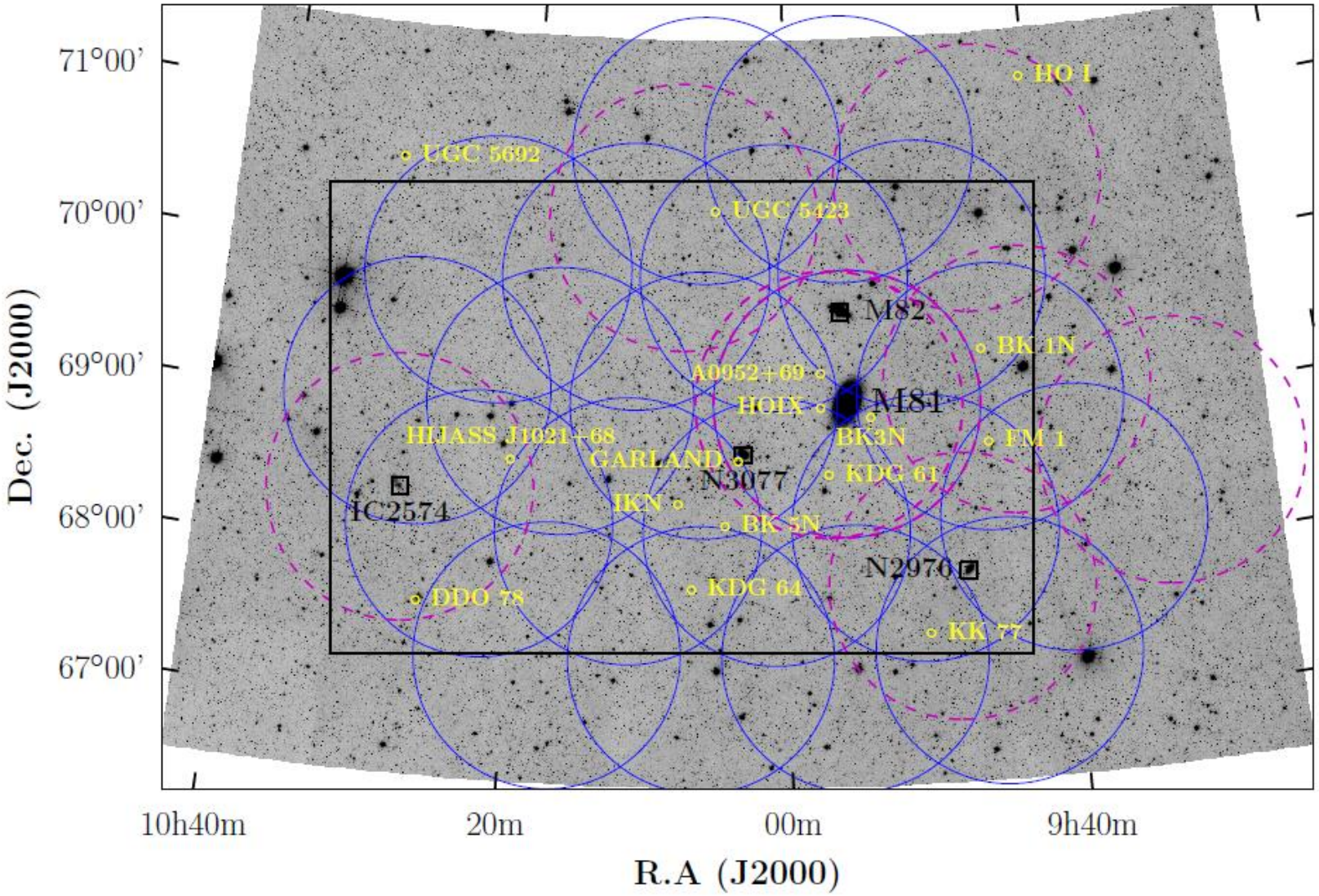


Figure 1. The mosaic fields observed with the DRAO ST overlaid on a *WISE* W1 grayscale image of the region. The *blue circles* show the original fields while the *magenta dashed circles* represent the archived data. The rectangle shows the area of the moment maps presented in Figs. 4, 6, 10 and 11. The major galaxies of the group are labelled in *black squares* while the dwarf galaxies are labelled in *yellow circles*.

<u>This paper, which is the first of a series, presents the global results of the deep Hi survey of the M81 group.</u>

To date, none of the existing deep Hi observations has ever covered an area of the group wide enough to include both the M81 system and the distant eastern member of the group, IC 2574. Located at a projected distance of 193 kpc from the centre of M81 group, the galaxy IC 2574 has a systemic velocity coinciding with that of the M81 system, which suggests a possible kinematical association with the system.

We use the Synthesis Telescope (ST) of the Dominion Radio Astrophysical Observatory2 (DRAO).

The DRAO ST consists of 7 antennas of 9m diameter each, arranged such that they form an east-west baseline with a maximum separation of 617.1m

To perform a short-spacing correction, we used single-dish data from the 100m Effelsberg telescope

The spectral and spatial resolutions are 5.2 km/s and 61'' respectively.

To increase the column density sensitivity of the observations, we have also produced a smoothed version of the cube, with a lower angular resolution of 1.8'. At the distance of M81, this translates to a physical resolution of 1.9kpc.

The average noise corresponds to a 1-sigma column density sensitivity of $1.1 \cdot 10^{18}$ cm^{-2} at a velocity width of 16 km/s. Because of its higher sensitivity, we will only use this smoothed version of the cube for the rest of the analysis in this paper.

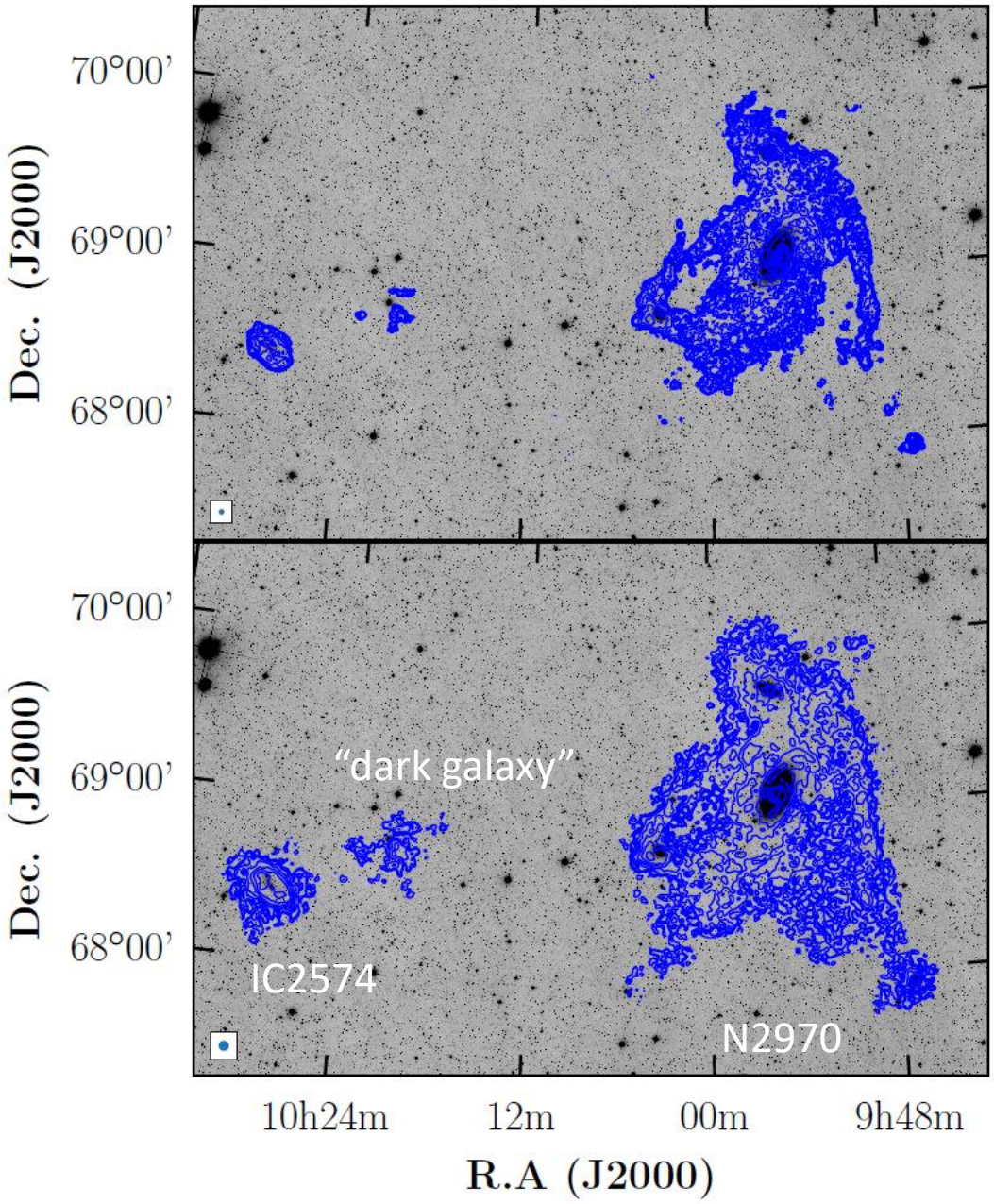


Figure 6. Column density maps of the full resolution (*top*) and smoothed 1.8′ (*bottom*) DRAO data overlaid on optical *WISE* W1 grayscale image. Contours are $1, 2, 4, \ldots, 128 \times 10^{19}$ cm^{-2}

The total HI mass of the galaxies in the M81 system is 3.5 10^9Ms, whereas the total HI mass detected in the field is 1.1 10^{10} Ms. This implies that only about 31% of the HI in the region resides in galaxies. The majority of the HI is

in the form of intergalactic gas and “lives" in structures like bridges, tails and clouds.

“Тёмная» карликовая галактика HIJASS J1021+68 (located west of IC 2574) has been reported in the blind Hi HIJASS survey (2001). The galaxy, which was previously observed to be a single concentration, appears to be surrounded by HI clouds of various sizes. It also appears to be connected to IC 2574. The high resolution DRAO mosaic allows to resolve the connection between the two galaxies, and it is clear that there exists a filament"-like complex of clouds connecting the two galaxies.

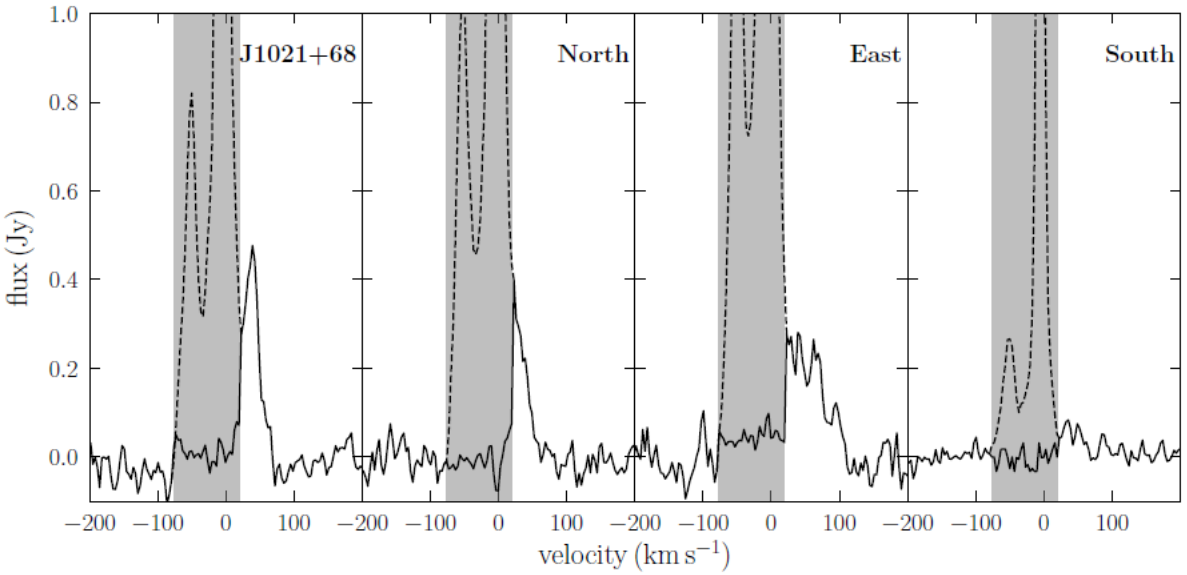


Figure 7. The HI profile of HIJASS J1021+68 (first panel) and those of the three neighbouring clouds (second to fourth panel) derived from the MW-subtracted datacube. The *dashed line* shows the global profile before MW subtraction. The grey shaded area represents the entire velocity range processed for MW subtraction.

Профили HIJASS J1021+68 и трех рядом расположенных облаков.

Although the systemic velocities of the clouds (and that of the dark galaxy as well) coincide with the MW emission, the profiles show that they are located in spectral regions that are not greatly affected by MW emission and therefore did not require a MW subtraction.

Contrarily to the profiles of HIJASS J1021+68 and associated clouds, the control spectra show no presence of broad Hi emission extending outside the MW-subtracted channels, showing that the clouds are most likely real and are not just remnant Galactic emission.

The derived HI mass of HIJASS J1021+68 is 3.50pm0.7 10^7Ms.

For the complex of small HI clouds lying east of the object, which seem to form a filament" towards IC 2574, we measured a total HI mass of 1.30pm5 10^7Ms.

- The northern cloud of HIJASS J1021+68, which seems to connect to the dark galaxy, has an HI mass of 1.6pm0.6 10^7Ms.

The existence of the optically dark galaxy HIJASS J1021+68 and its connection with IC 2574 further supports the hypothesis of interaction of IC 2574 with the system. In fact, Boyce et al. (2001) hinted that HIJASS J1021+68 is a possible tidal dwarf galaxy in which star formation has not begun.

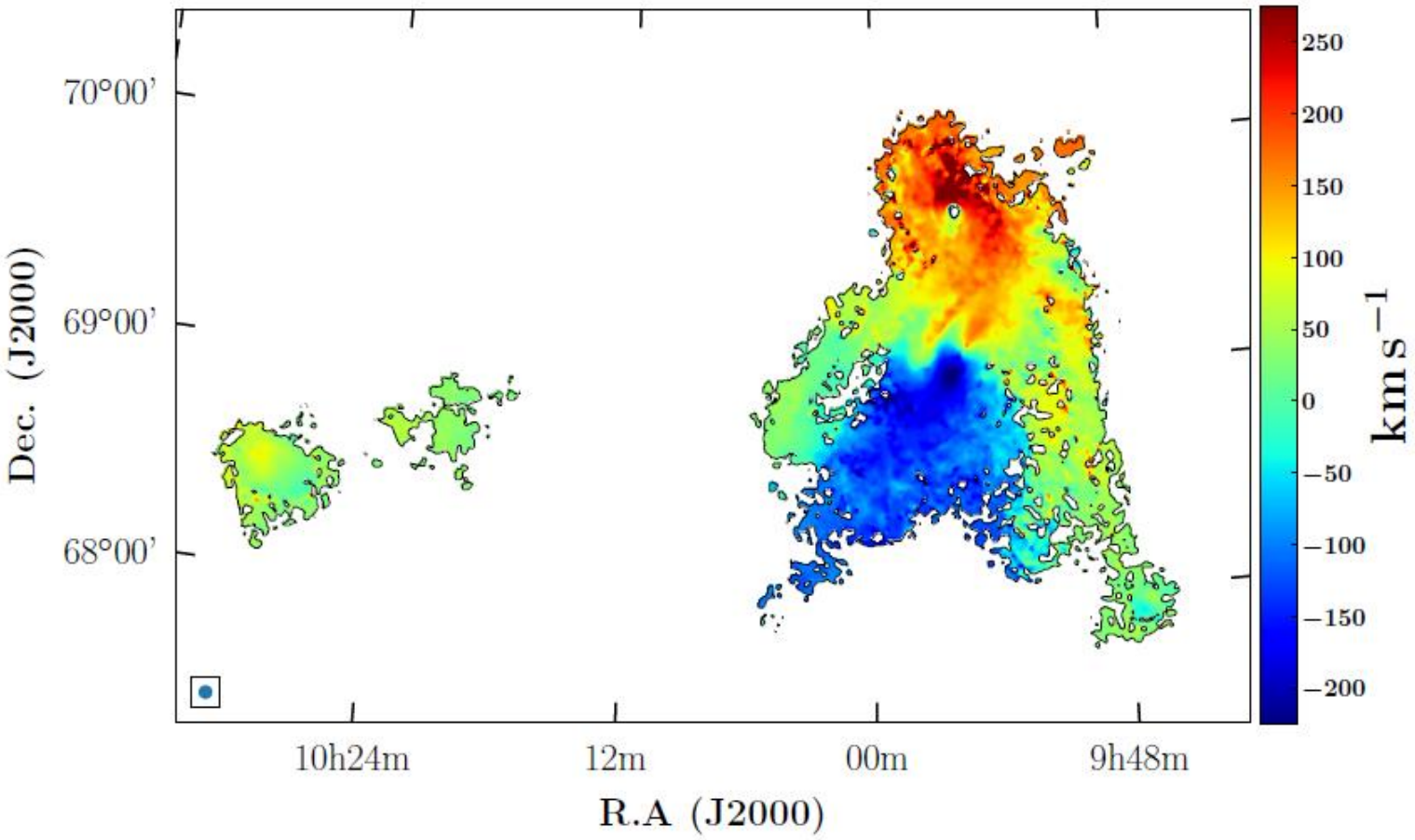
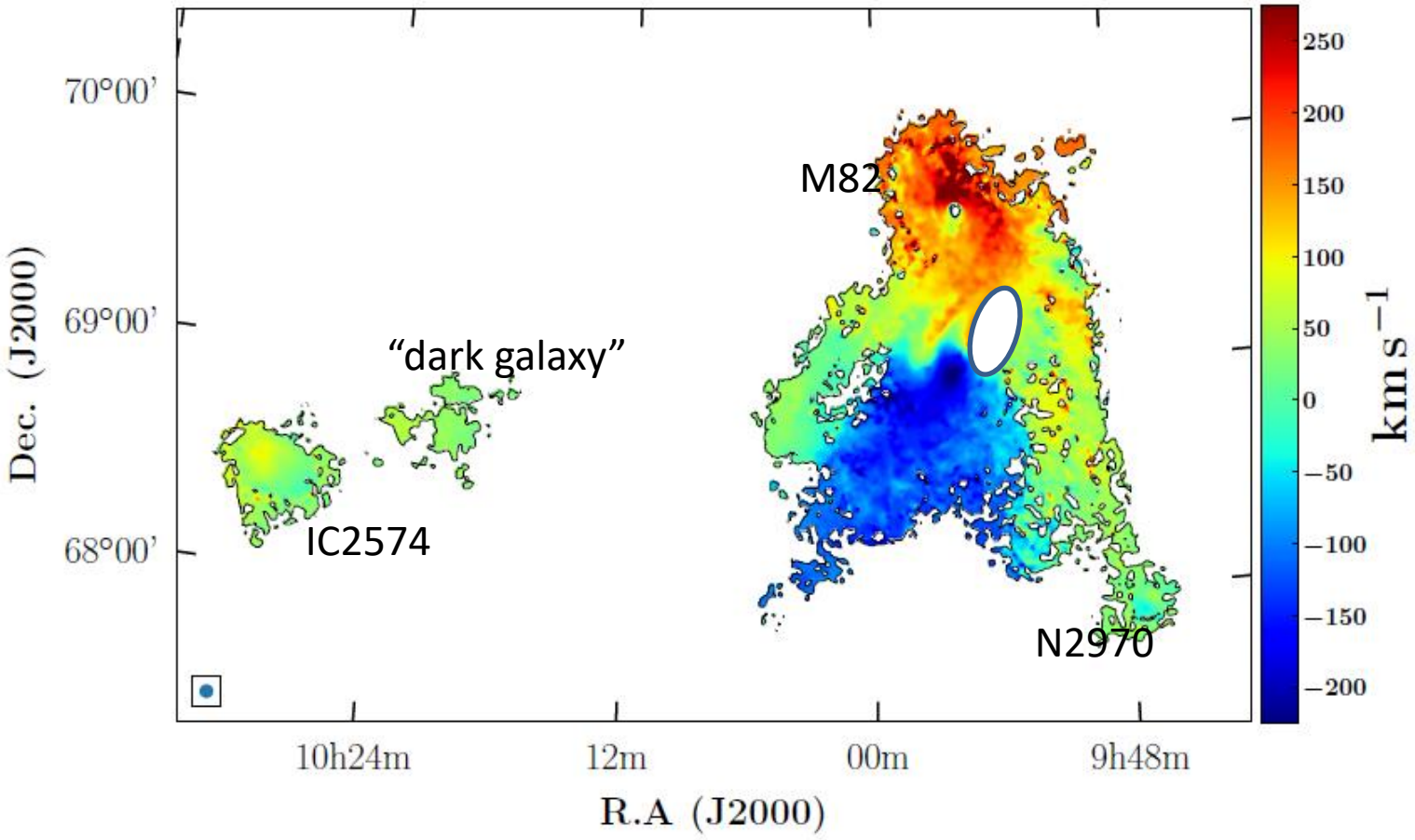


Figure 10. The intensity weighted velocity field of the M81 group derived from the DRAO 1.8′ resolution datacube. The contour corresponds to the 1×10^{19} cm^{-2} column density level.



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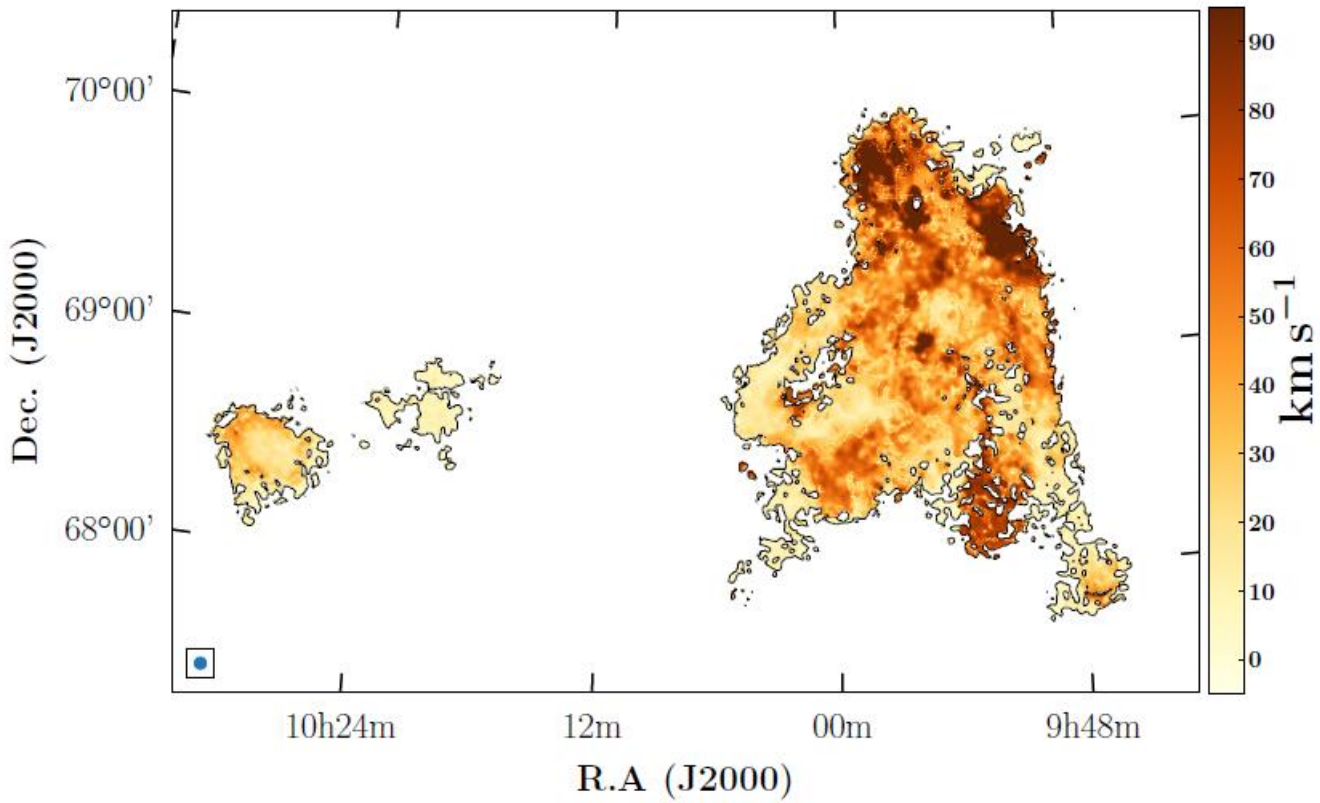


Figure 11. The velocity dispersion map of the M81 group derived from the DRAO 1.8′ resolution datacube. The contour corresponds to the $1 \times 10^{19}\,\mathrm{cm}^{-2}$ column density level.

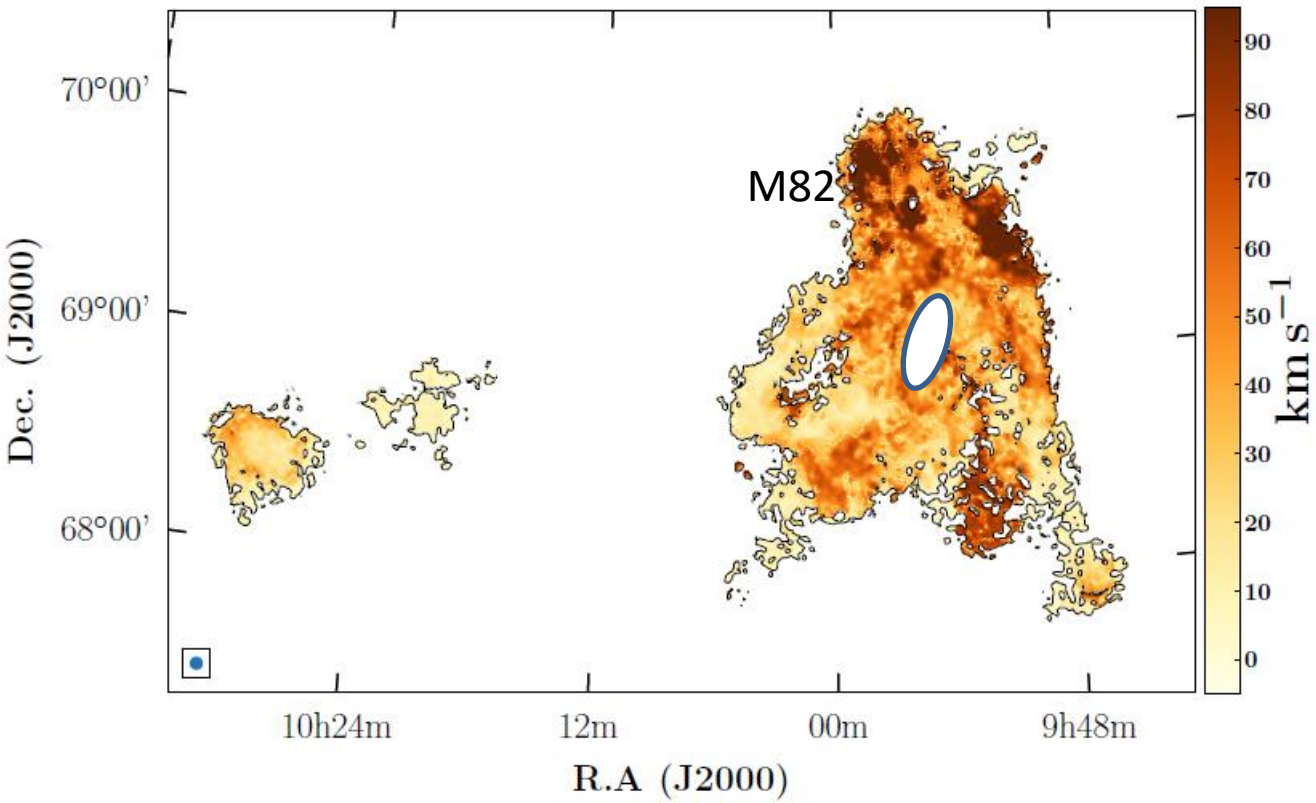


Figure 11. The velocity dispersion map of the M81 group derived from the DRAO 1.8′ resolution datacube. The contour corresponds to the $1 \times 10^{19}\,\mathrm{cm}^{-2}$ column density level.

The discrepancy between the system's rotation curve derived in this work and those of the literature is likely an effect of beam smearing due to the lower resolution of our data

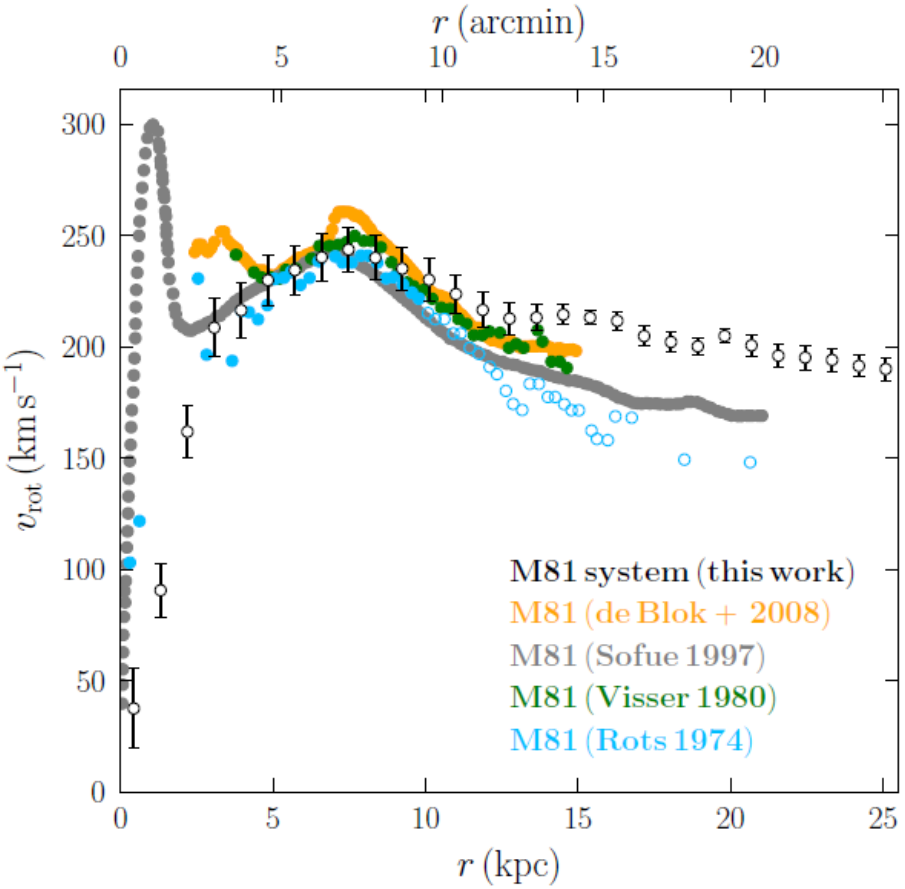


Figure 15. Rotation curves of the M81 galaxy from the literature, compared to that of the M81 system in the inner 25 kpc. The *open circles* of Rots (1974) correspond to the approaching side of the galaxy.

The velocity field of the complex suggests a large-scale, ordered motion of the galaxies around the M81 galaxy, with the receding northern part that contains M82 and A0952+69 (the Arp's loop), while the southern part approaches the observer. It is thus tempting to try an idealised kinematic model to the velocity field, like the usual tilted-ring model.

The observed velocity is therefore the projection of the rotation and radial velocities along the line-of-sight, and can be written

$$v_{obs} = v_{sys} + v_{rot} \sin i \cos + v_{rad} \sin i \sin ;$$

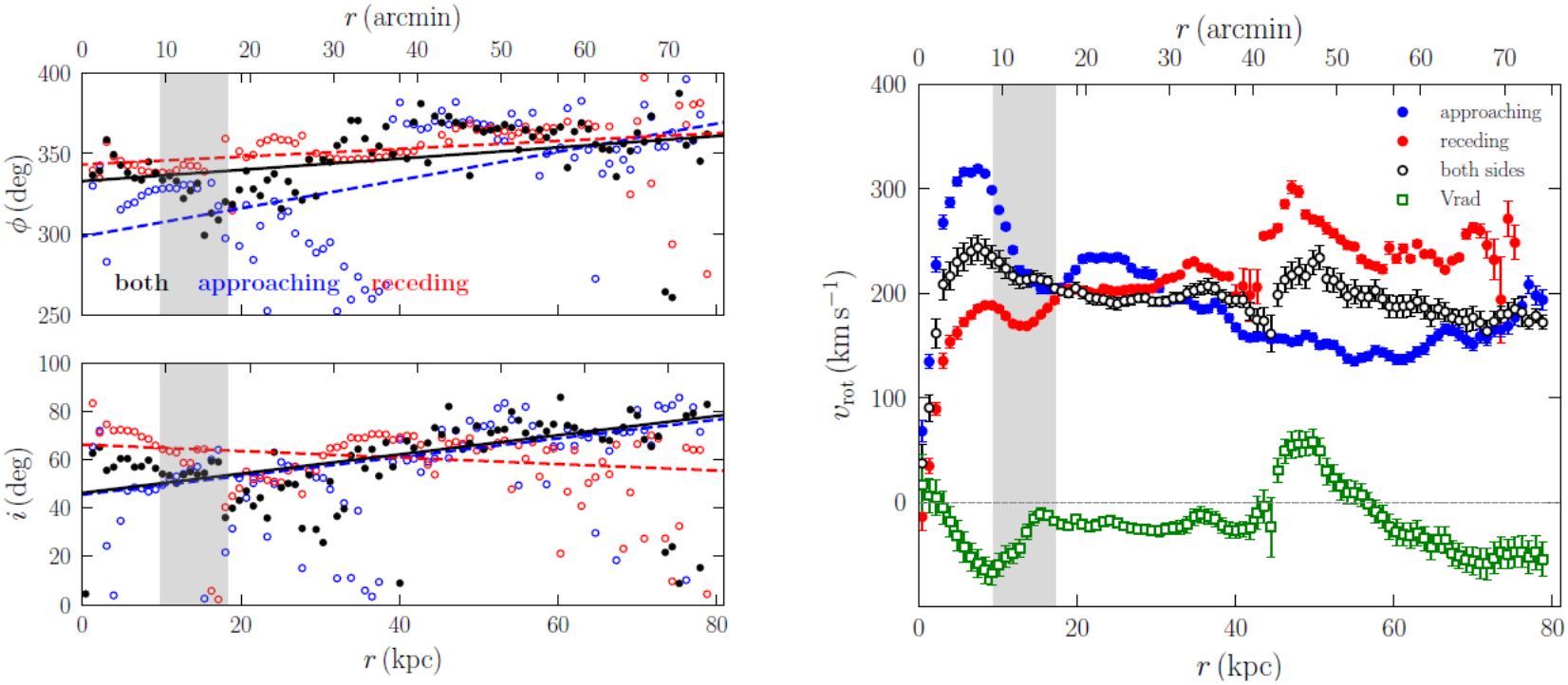
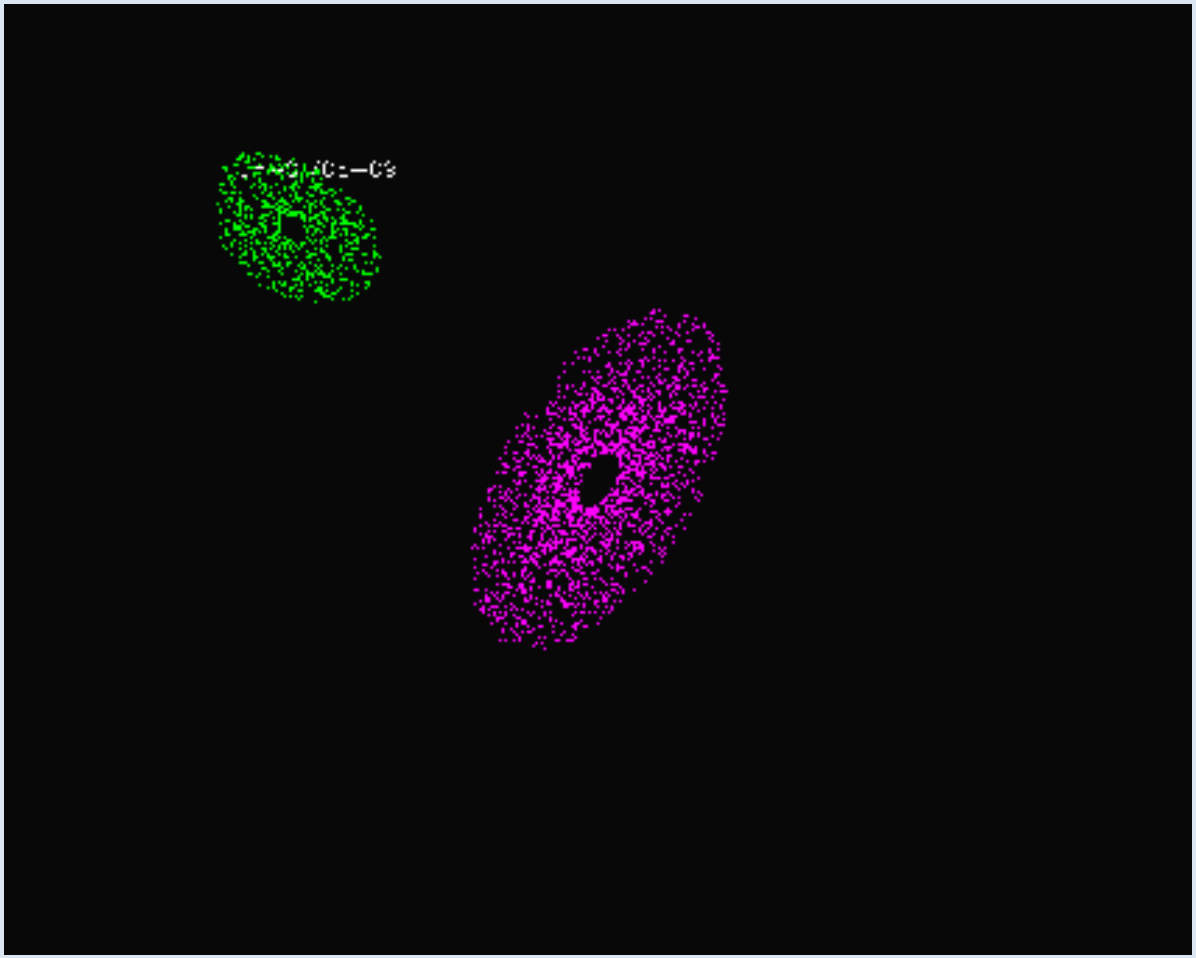


Figure 14. *Left panel:* The variations of the position angle (*top*) and the inclination (*bottom*) as a function of the radius in the tilted-ring model of the M81 system; *right panel:* Rotation curve of the M81 system derived using the tilted-ring model. The *green dots* show the variations of the radial velocities. The grey area in both panels corresponds to the position of HoIX.

The simulation used in Yun (1999) successfully reproduces both the spatial distribution of the high column density Hi gas in the system.



Основные выводы

1. Подтверждается:

the interacting three major galaxies of the group (M81, M82 and NGC 3077) are connected through Hi bridges and intergalactic Hi clouds.

2. The HI mosaic in the present work suggests that the connection between the galaxy and IC 2574 (previously hinted by Boyce et al. 2001) is through a filament" of small clouds spanning the space between the two galaxies.

3. In the tilted-ring model the outermost gas and galaxies looks rotating at the same speed as the inner disk of M81. Although the velocities of the approaching and receding sides of the system differ, the flat trend corroborates the assumption of a large-scale rotating system dominated by M81.