Probing the magnetic field of the nearby galaxy pair Arp 269

B. Nikiel-Wroczyński⋆, M. Jamrozy, M. Soida, M. Urbanik, and J. Knapik
Astronomical Observatory, Jagiellonian University, ul. Orla 171, Kraków PL 30-244, Poland

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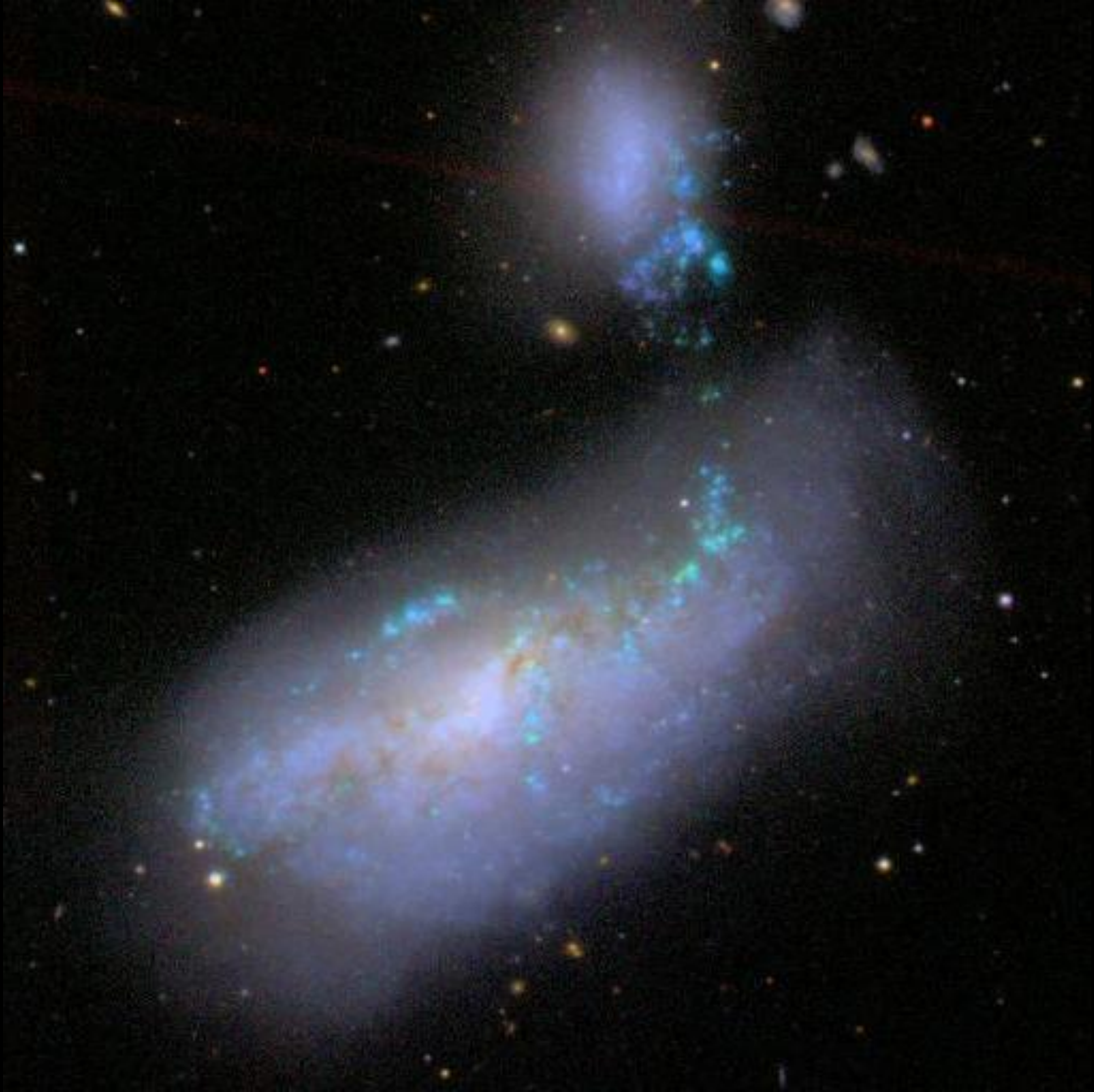
ABSTRACT

We present a multiwavelength radio study of the nearby galaxy pair Arp 269 (NGC 4490/85). High sensitivity to extended structures gained by using the merged interferometric and single dish maps allowed us to reveal a previously undiscovered extension of the radio continuum emission. Its direction is significantly different from that of the neutral gas tail, suggesting that different physical processes might be involved in their creation. The population of radio-emitting electrons is generally young, signifying an ongoing, vigorous star formation – this claim is supported by strong magnetic fields (over 20 μG), similar to the ones found in much larger spiral galaxies. From the study of the spectral energy distribution we conclude that the electron population in the intergalactic bridge between member galaxies originates from the disk areas, and therefore its age (app. 3.7–16.9 Myrs, depending on the model used) reflects the timescale of the interaction. We have also discovered an angularly near Compact Steep Source – which is a member of a different galaxy pair – at a redshift of approximately 0.125.

Key words: galaxies: magnetic fields – galaxies: individual: NGC 4490, NGC 4485 – galaxies: pairs: individual: VV 030, Arp 269 – galaxies: interactions – intergalactic medium – radio continuum: galaxies

1 INTRODUCTION

Among the diversity of forms that intergalactic structures can adopt, giant gaseous tails and streams accompanying galaxy interactions constitute one of the most impressive phenomena. Widespread, dense and wide, they are able to transport matter tens of kiloparsecs away from the are collisionally coupled to (see eg. Mestel & Spitzer 1956, or Mouschovias & Paleologou 1981 and references therein). Therefore, it might be expected that the neutral gas tail can be accompanied by a magnetised outflow. Ability to transport gas far away from the intra-system medium gives a possibility that also the magnetic field – frozen into the



Задача

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В приливных хвостах и перемычках может существовать поле, вмороженное в газ.

Поиск нетеплового излучения и измерение H-поля в системе Arp 269, где “the interaction is just started”.

Наблюдения:Effelsberg+ VLA+GMRT

на ряде частот 0.61-22.4 GHz. (сочетание высокой чувствительности с высоким разрешением). Разделение на тепловое и не-тепловое РИ.

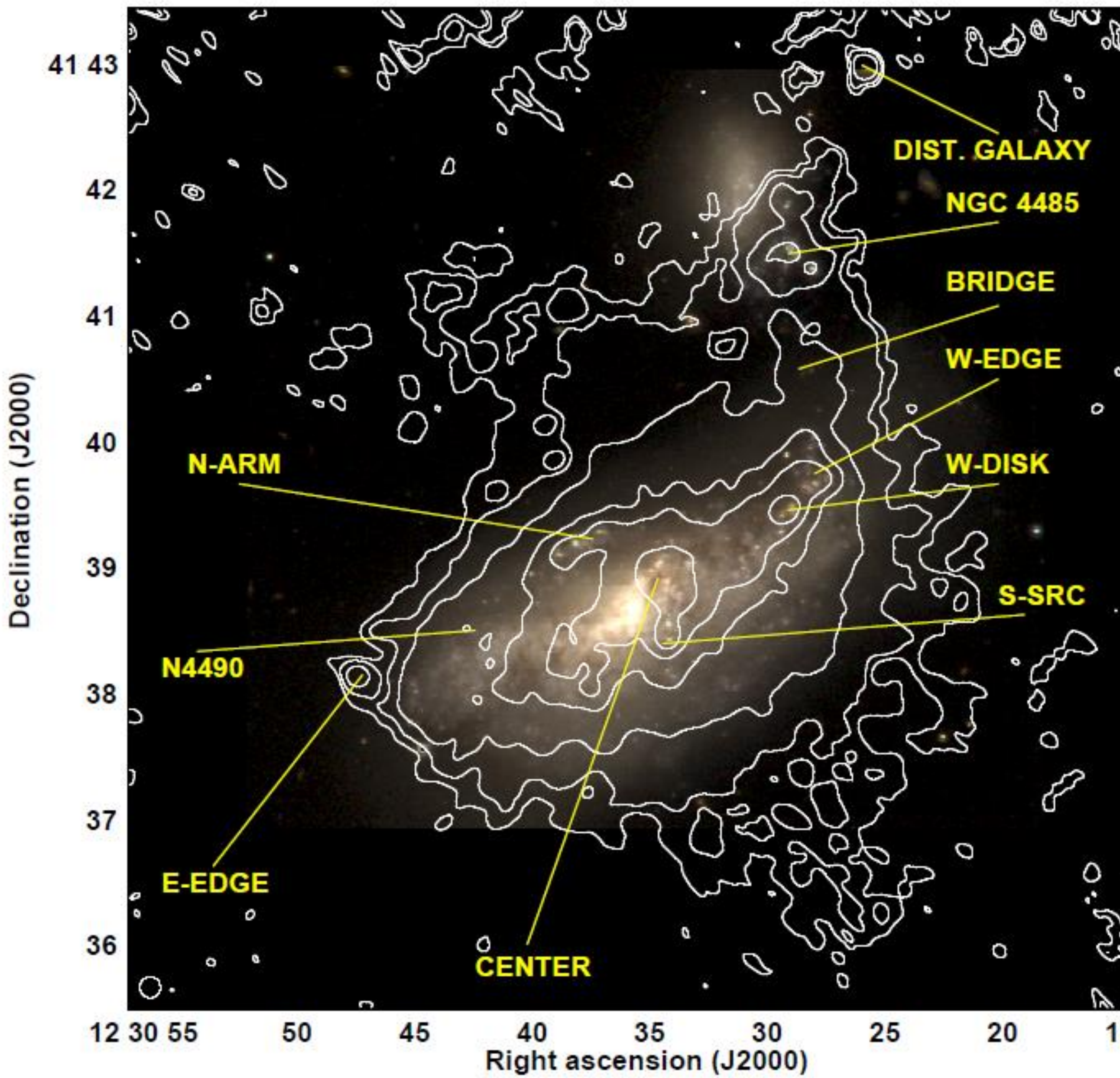
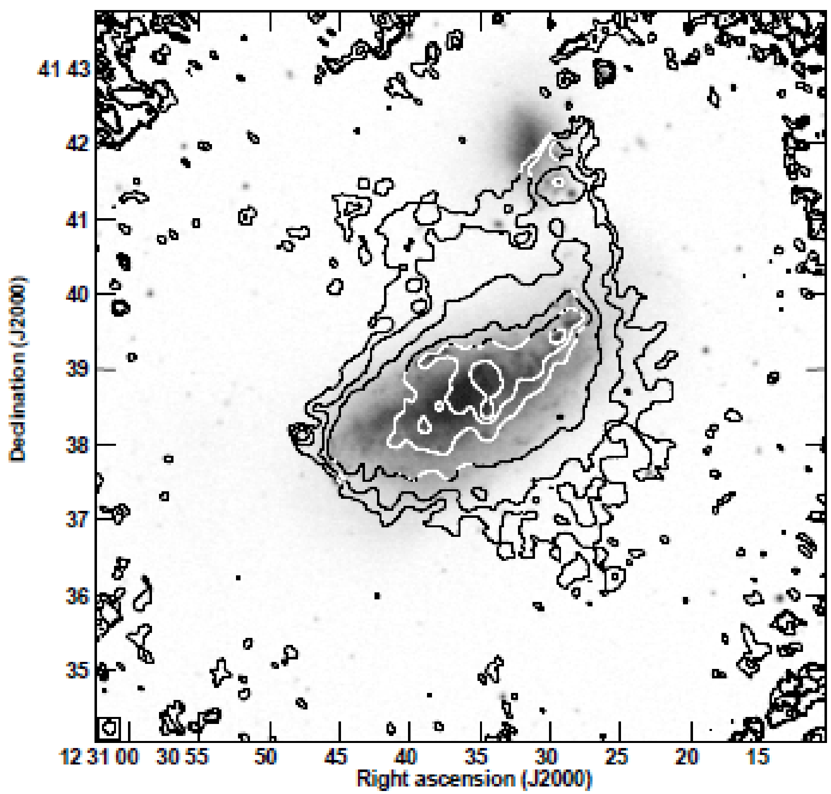
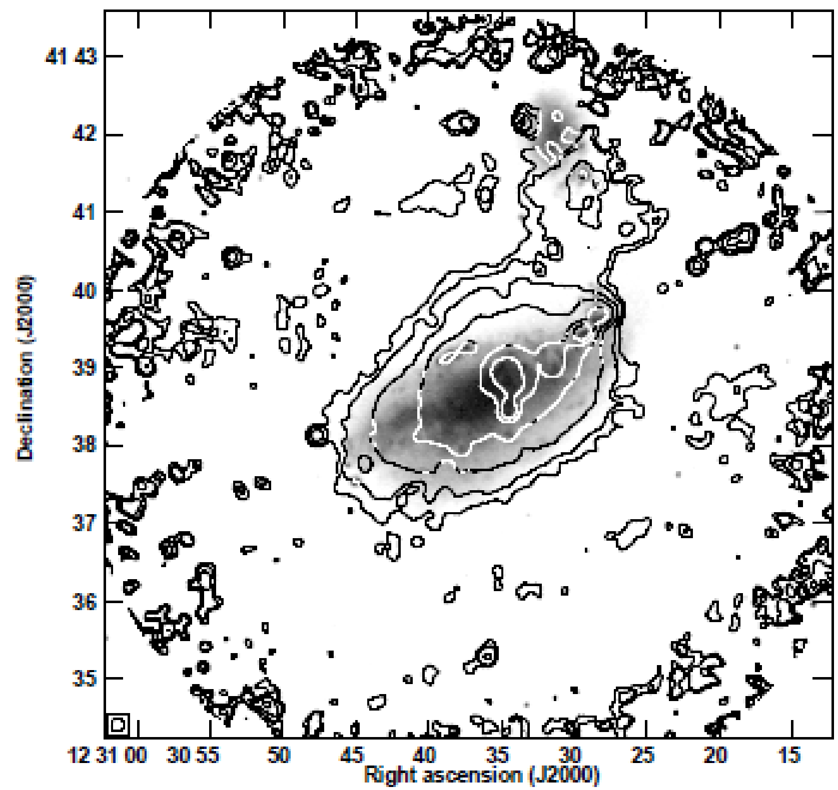


Figure 1. Merged VLA + Effelsberg map of the TP emission at 4.86 GHz overlaid upon an RGB image, with positions of the regions discussed in this paper indicated. The contour levels are $3, 5, 10, 25, 50, 100\times$ $33\,\mu$Jy/beam (first contour at 2.5 times the r.m.s. noise level). The angular resolution is 10 arcsec. The beam is represented by a circle in the lower left corner of the image. Details of the maps used to produce this RGB composite can be found in the text (Sect. 3).

На разных частотах галактика выглядит по разному



(c) Effelsberg+VLA map at 4.86 GHz. The r.m.s. noise level is 40μJy/beam.



(d) Effelsberg+VLA map at 8.44 GHz. The r.m.s. noise level is 55μJy/beam.

Хвосты HI +
Не-тепловое РИ.
ХВОСТ – НЕ-ПРИЛИВНОЙ?

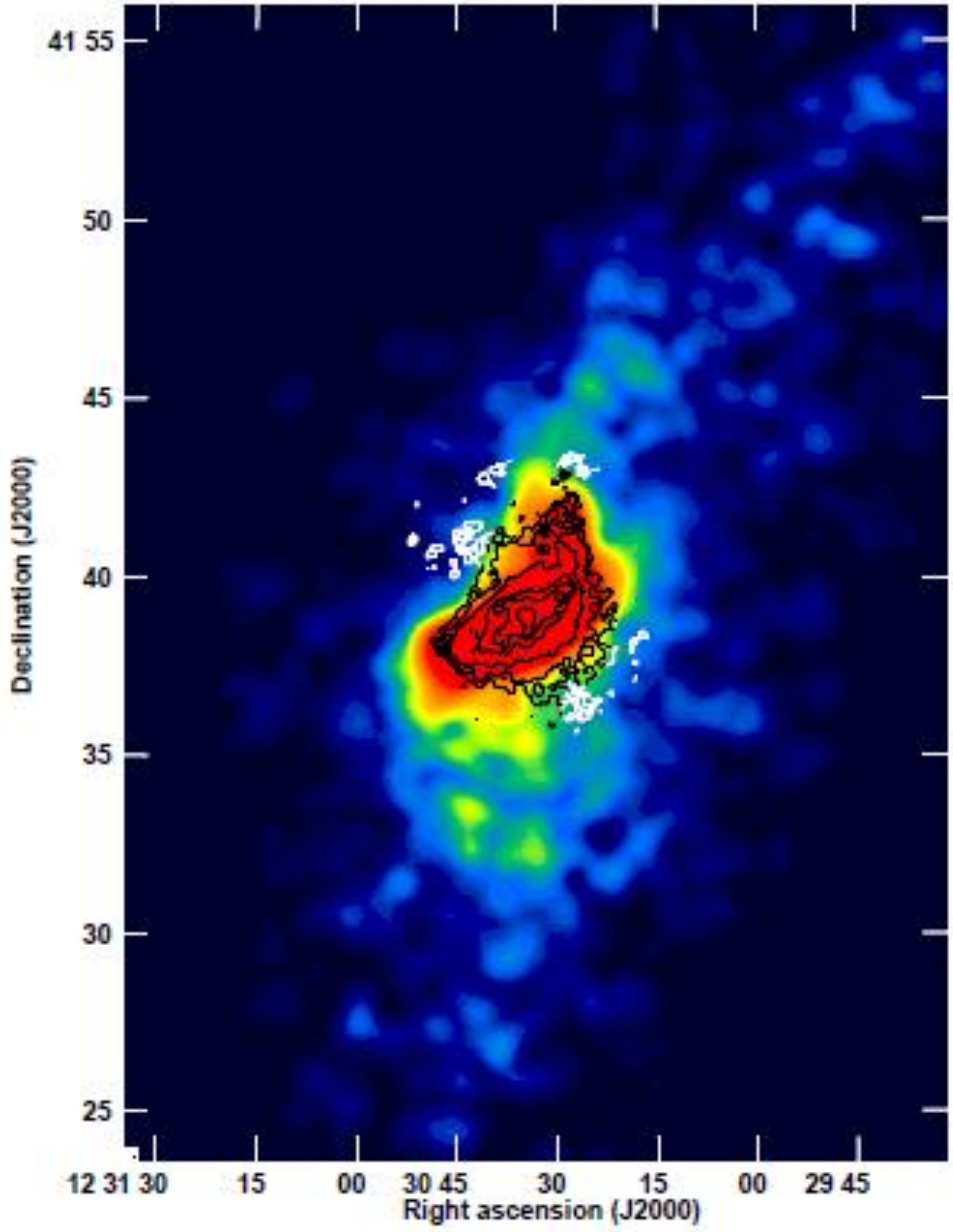


Figure 5. Contours of the 4.86 GHz radio emission superimposed on the neutral hydrogen distribution map from Swaters et al. (2002), taken from the NED database. The contour levels are

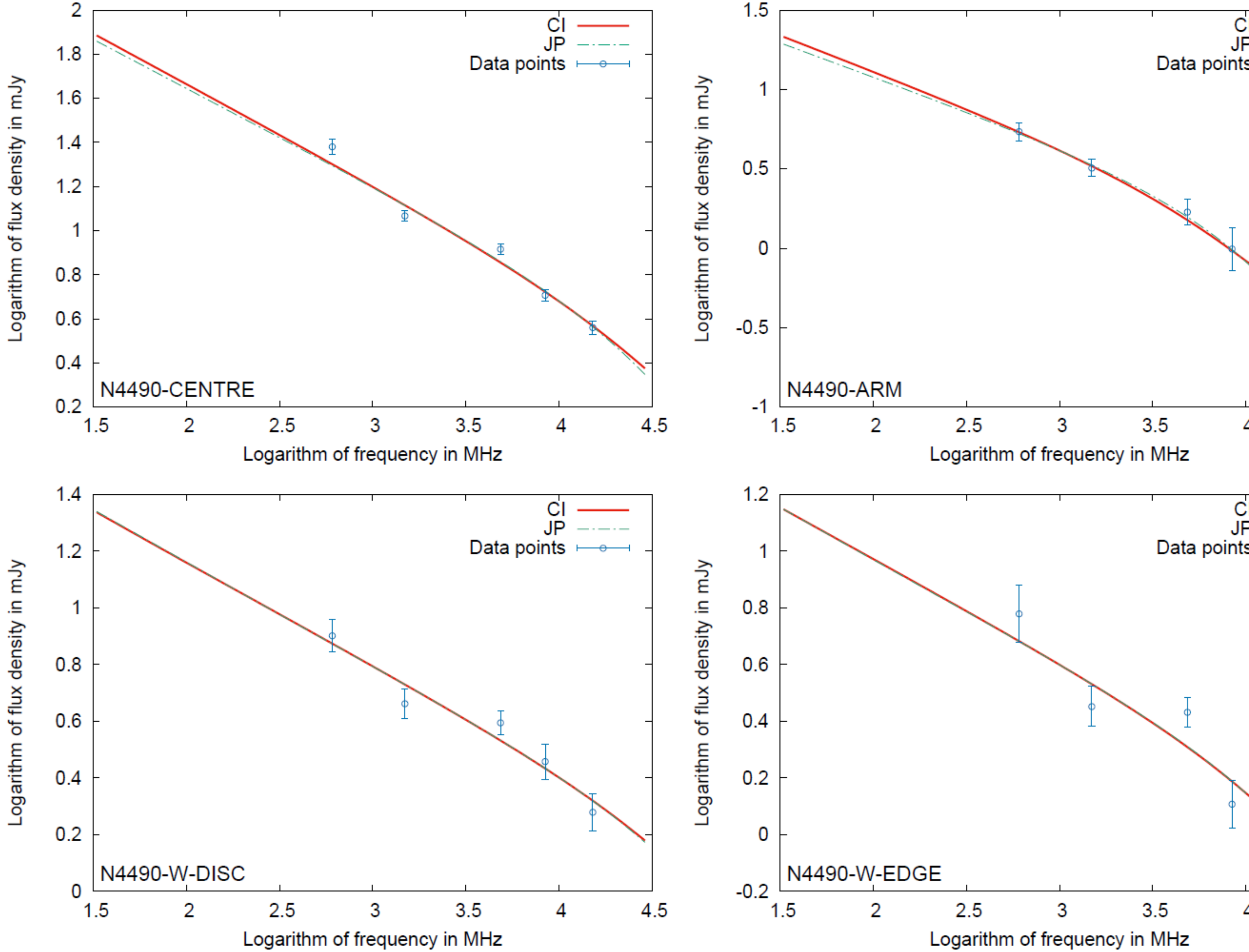


Figure 4. Fitted Jaffe-Perola (dashed line) and Continuous Injection (solid line) model curves for the various region

Region	α_{NTH}	B_{TOT} [μG]	Age (JP) [Myr]	Age (CI) [Myr]
Total	0.70	21.9 ± 2.9	2.4 – 5.7	3.8 – 14.9
Sm. Disk	0.71	21.5 ± 2.8	2.9 – 6.5	3.9 – 15.1
NGC 4485	0.80	15.5 ± 2.0	< 7.8	< 23.5
Bridge	0.72	18.3 ± 2.0	3.7 – 7.9	4.5 – 16.9
N-Arm	0.56	25.5 ± 3.5	0.4 – 4.9	0.6 – 15.1
Center	0.51	39.3 ± 5.4	< 1.4	< 2.8
E-Edge	0.76	21.7 ± 2.8	< 2.4	< 4.7
W-Disk	0.61	26.0 ± 3.5	< 2.0	< 3.7
W-Edge	0.84	18.2 ± 2.3	< 4.7	< 6.8

Основные результаты

- Мощное радиоизлучение главной галактики – результат недавно начавшейся вспышки SF.
- Радиоизлучение за пределами галактики исходит не из хвостов, а из областей, прилегающих к галактике, и вытянутых перпендикулярно хвостам. Природа выброса как и природа хвостов, не очень понятна.
- Измерено магнитное поле в галактиках. Оно- необычно сильное (22 muG). Причина – интенсивное звездообразование. Возраст – неск. Myr.
- В перемычке имеется поле, возраст электронов

низкий, и соответствует времени активного взаимодействия (менее 17 Myr).

Another piece of the puzzle: the fast H I outflow in Mrk 231

Raffaella Morganti[1,2], Sylvain Veilleux[3], Tom Oosterloo[1,2], Stacy H. Teng[4], David Rupke[5]

[1] Netherlands Institute for Radio Astronomy, Postbus 2, 7990 AA, Dwingeloo, The Netherlands
[2] Kapteyn Astronomical Institute, University of Groningen, Postbus 800, 9700 AV Groningen, The Netherlands
[3] Department of Astronomy, Joint Space-Science Institute, University of Maryland, College Park, MD 20742, USA
[4] Science and Technology Division, Institute for Defense Analyses, Alexandria, VA 22311, USA
[5] Department of Physics, Rhodes College, Memphis, TN 38112, USA

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ABSTRACT

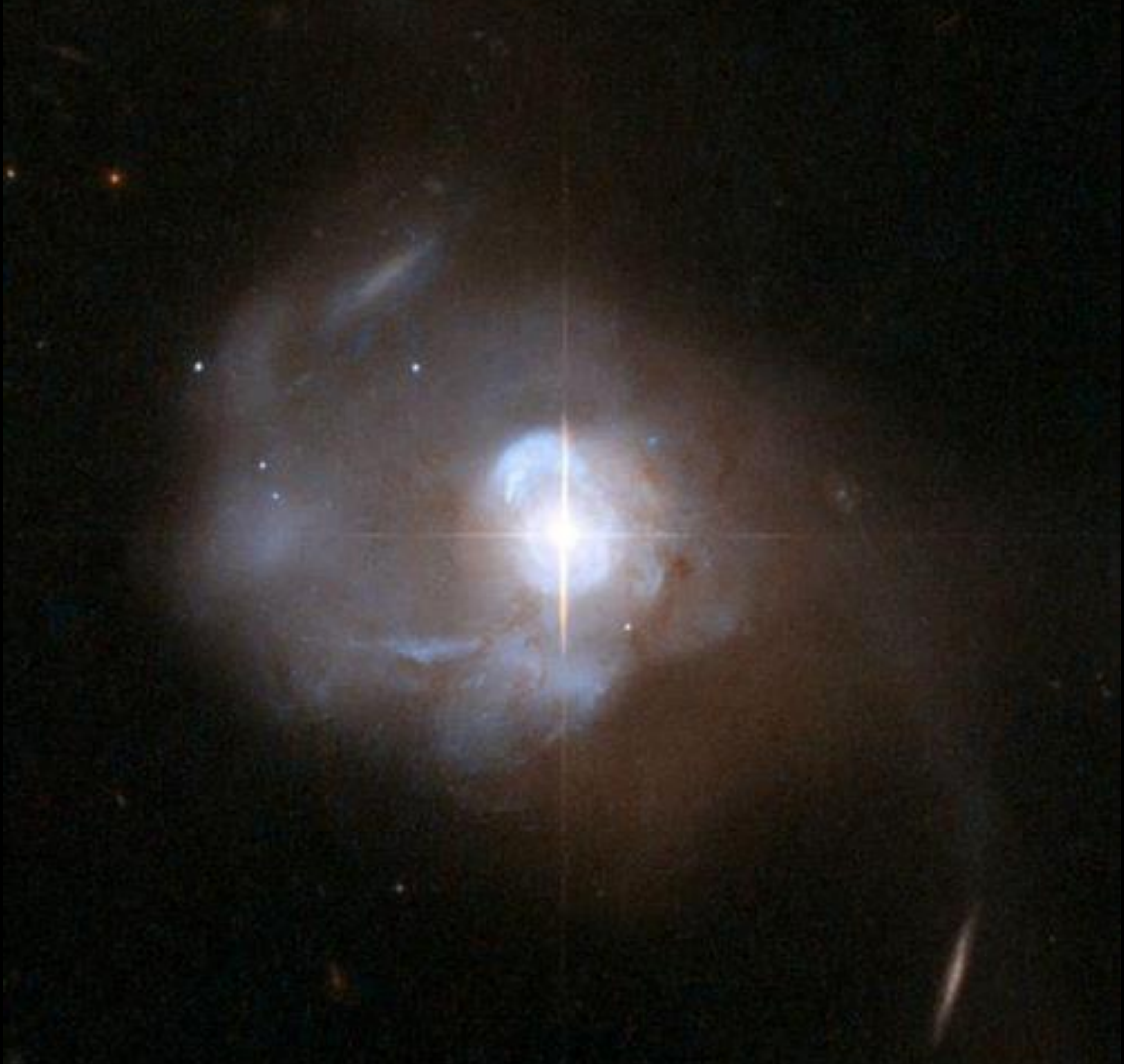
We present the detection, performed with the Westerbork Synthesis Radio Telescope (WSRT) and the Karl Jansky Very Large Array (VLA), of a fast H I 21cm outflow in the ultra-luminous infrared galaxy Mrk 231. The outflow is observed as shallow H I absorption blueshifted $\sim$1300 km s^{-1} with respect to the systemic velocity and located against the inner kpc of the radio source. The outflowing gas has an estimated column density between 5 and $15 \times 10^{18} T_{\rm spin}$ cm^{-2}. We derive the $T_{\rm spin}$ to lie in the range 400 – 2000 K and the corresponding H I densities are $n_{\rm HI} \sim 10 - 100$ cm^{-3}. Our results complement previous findings and confirm the multiphase nature of the outflow in Mrk 231. Although effects of the interaction between the radio plasma and the surrounding medium cannot be ruled out, the energetics and the lack of a clear kpc-scale jet suggest that the most likely origin of the H I outflow is a wide-angle nuclear wind, as earlier proposed to explain the neutral outflow traced by Na I and molecular gas in this source. Our results suggest that an H I component is present in fast outflows regardless of the acceleration mechanism (wind *vs* jet driven) and that it must be connected with common properties of the pre-interaction gas involved. Considering the observed similarity of their column densities, the H I outflow likely represents the inner part of the broad wind identified on larger scales in atomic Na I. The mass outflow rate of the H I outflow (between 8 and 18 $M_\odot$ yr^{-1}) does not appear to be as large as the one observed in molecular gas, partly due to the smaller sizes of the outflowing region sampled by the H I absorption. These characteristics are commonly seen in other cases of AGN-driven outflows suggesting that the H I may represent a short intermediate phase in the rapid cooling of the gas. The results further confirm H I as a good tracer for AGN-driven outflows not only in powerful radio sources. We also obtained deeper continuum images than previously available. They confirm the complex structure of the radio continuum originating both from the AGN and star formation. At the resolution obtained with the VLA ($\sim$1″) we do not see a kpc-scale jet. Instead, we detect a plateau of emission, likely due to star formation, surrounding the bright nuclear region. We also detect a poorly collimated bridge which may represent the channel feeding the southern lobe. The unprecedented depth of the low-resolution WSRT image reveals radio emission extending 50″ (43 kpc) to the south and 20″ (17 kpc) to the north.

Key words. galaxies: active - galaxies: individual: Mrk231 - ISM: jets and outflow - radio lines: galaxies

1. Cold gas and fast, massive outflows

AGN-driven outflows have recently attracted considerable attention for their potential impact on galaxy evolution because they may play an important role in regulating star forma- the main open questions is the presence of large amounts of cold gas participating in these multi-phase AGN-driven outflows.

Different mechanisms have been proposed to accelerate the gas. The most widely considered are wide-angle,



Mrk231

- Ближайший квазар (V=12600 км/с).

Merger. AGN. ULIRG (SFR=160Ms/yr).

Уже обнаружены:

molecular gas mass outflow (50-1000 Ms/yr within 1 kpc), Na I outflow (up to 3 kpc from the centre), широкий blueshifted component HI in absorption.

Локализация не ясна.

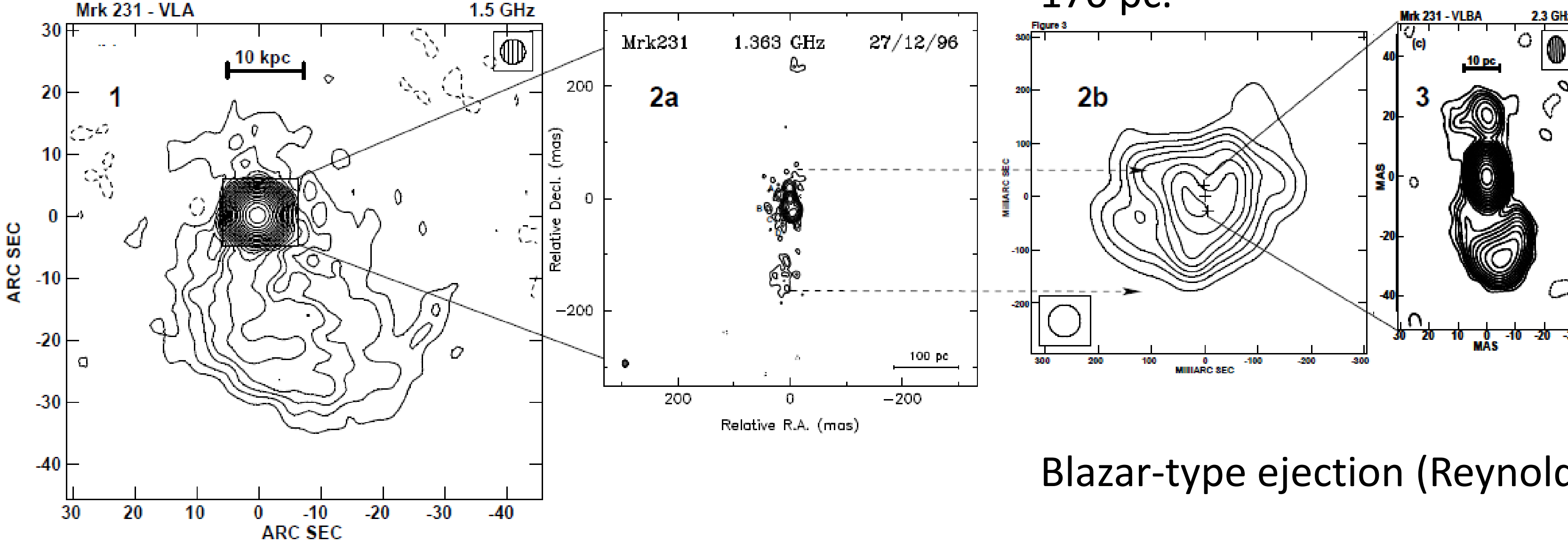
Radiosource – мощность промежуточная между сейфертами и радиогалактиками.. Быстрая переменность.

Два механизма outflow:

Wind-driven outflow (тепловая плазма _ давление радиации)

Radioplazma (jet) emanating from AGN.

«РАДИОДИСК»
170 pc.



Blazar-type ejection (Reynolds+,2009).

Fig. 1. Overview of the radio continuum structures of Mrk 231 ranging from tens of kpc to the inner tens of pc regions (at the distance of Mrk 231 1″ corresponds to 0.867 kpc). The images, taken from Ulvestad, Wrobel, & Carilli (1999); Carilli et al. (1998); Taylor et al. (1999) (©AAS, reproduced with permission), show the presence of different structures, see text for details. The disk-like structure (Panels 2b) aligned almost E-W has been detected after the subtraction of the brighter nuclear structure (Panel 3). For details, see description in the text.

Новые наблюдения

WSRT. 12”x10”.

VLA 0.9”0.9” HI outflow. FWHM= 837 km/s.

Положение: в пределах 1 кпс от ядра.

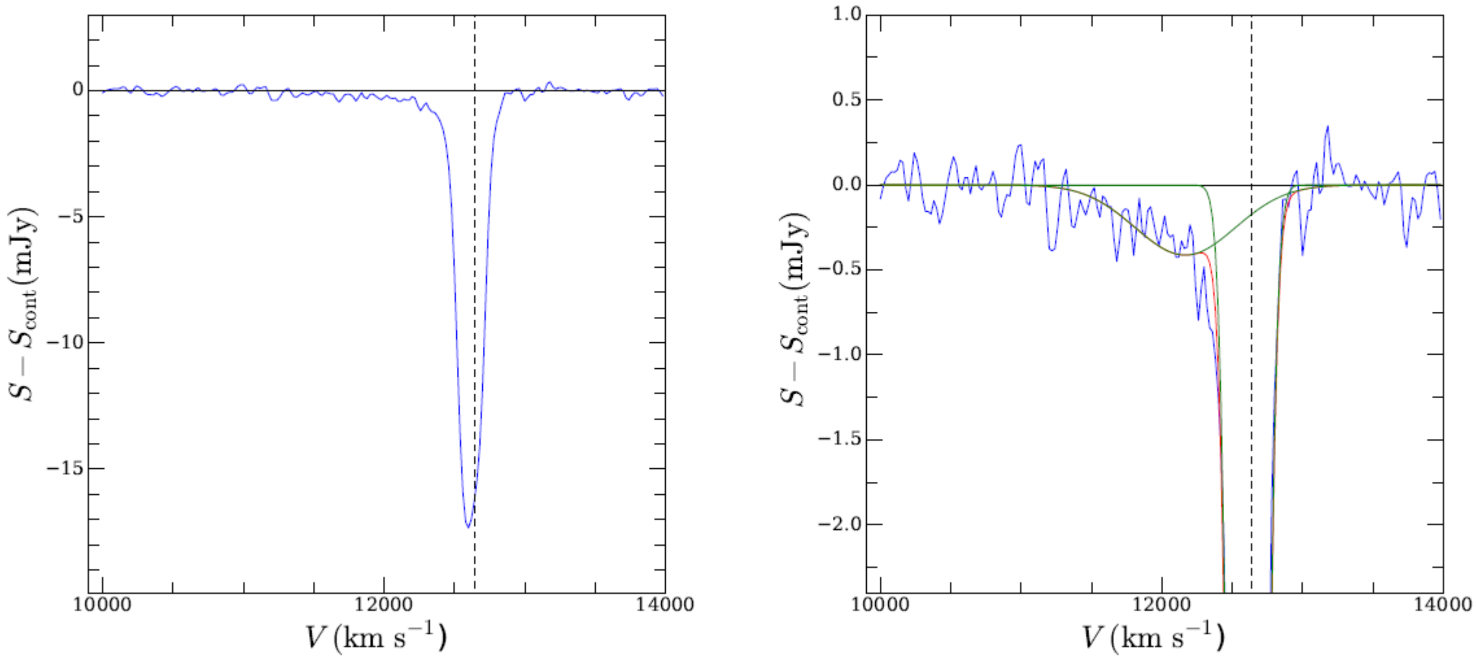


Fig. 4. Left: H I absorption profile from the VLA data. The shallow broad absorption is visible at velocities below ~ 12250 $\rm km\,s^{-1}$. The dashed line indicate the systemic velocity of Mrk 231. **Right:** Zoom-in of the H I absorption profile from the VLA data. that better shows the blueshifted wing. Superposed is the Gaussian fit of the broad component discussed in the text.

- Разрешение недостаточно, чтобы понять, отнисится ли blueshifted HI к радиодиску, или к компктным радиовыбросам.
- Рассматриваются оба случая. Результирующие оценки
- n_HI= 10-100 cm-3. dM/dt = 8-18 Ms/yr.

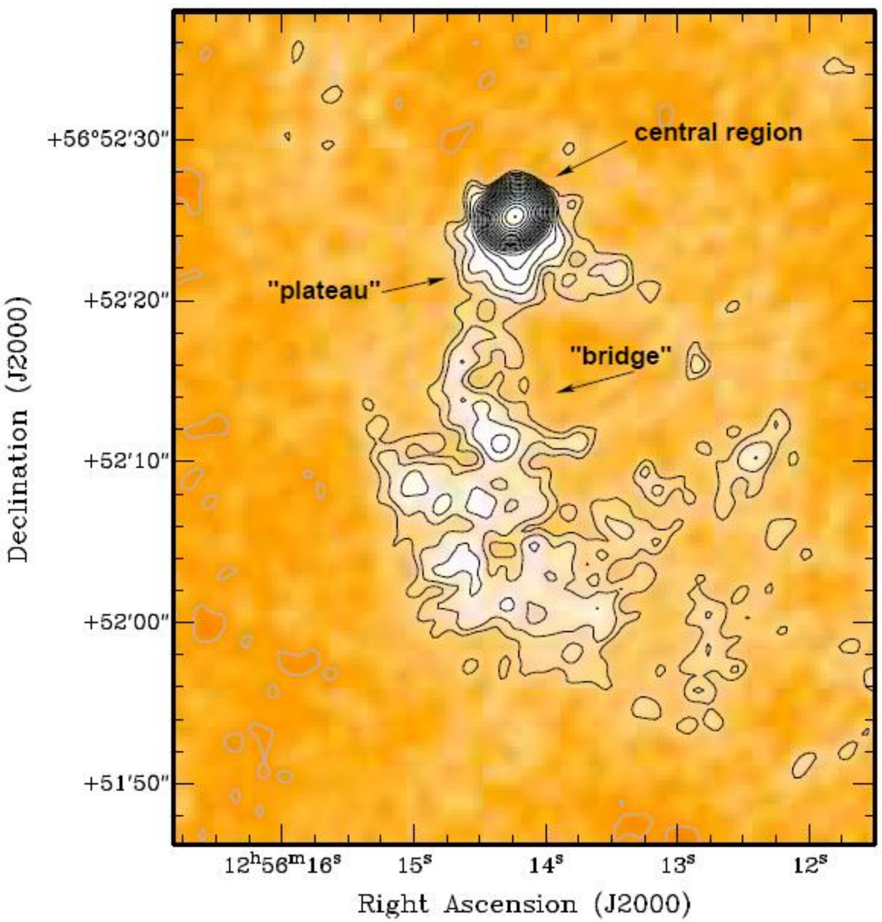


Fig. 6. Radio continuum image obtained from the VLA data using robust 0.5 weighting (1″ = 0.867 kpc). The different components (bright core, "plateau", bridge structure in the southern lobe) are clearly visible. See text for details. The contour levels range from −0.07, 0.07 mJy beam^{-1} to 250 mJy beam^{-1} with increasing factors of 1.5.

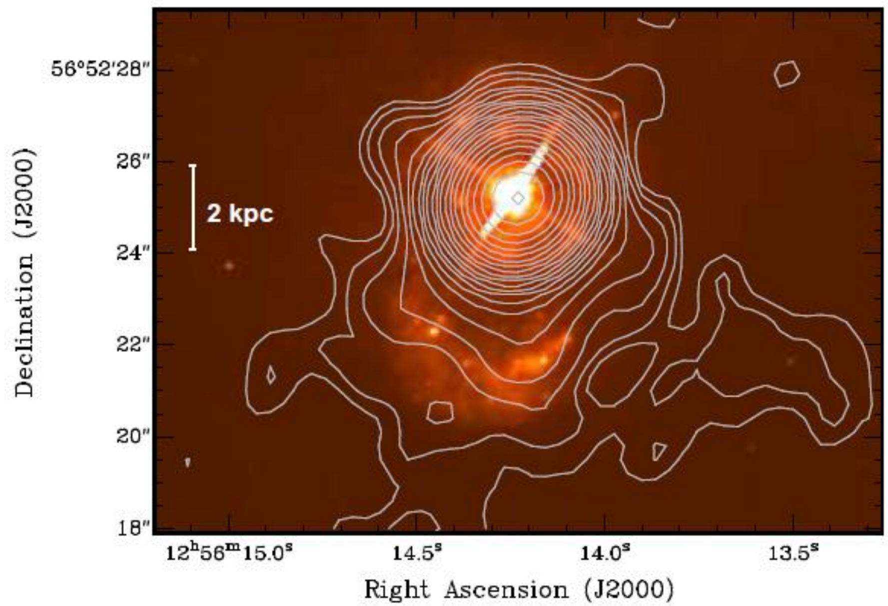


Fig. 7. Zoom-in of the central region of the radio source. Radio contours from the VLA image of Mrk 231 are superposed to the false colour HST WFC image made from the F814W (red) and F435W (blue) data. The image illustrating the spatial coincidence of the radio plateau and the optical arc feature shown by HST, representing a region of star formation.

HST+radiocont+X-ray(Chandra)

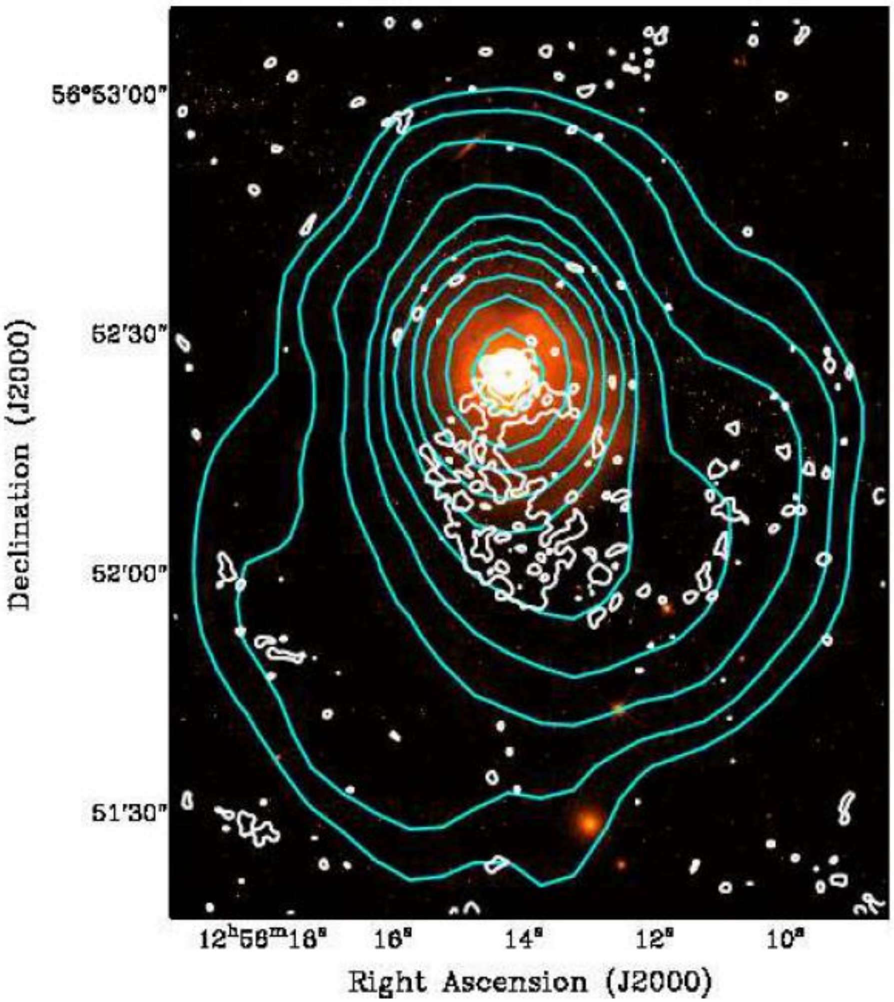


Fig. 8. HST image with superimposed the WSRT (cyan) and the VLA (white) radio contours. The figure illustrate the extension of the large scale structure of the continuum emission recovered by lower spatial resolution of the WSRT image. Contours like in Fig.6 and Fig.3.

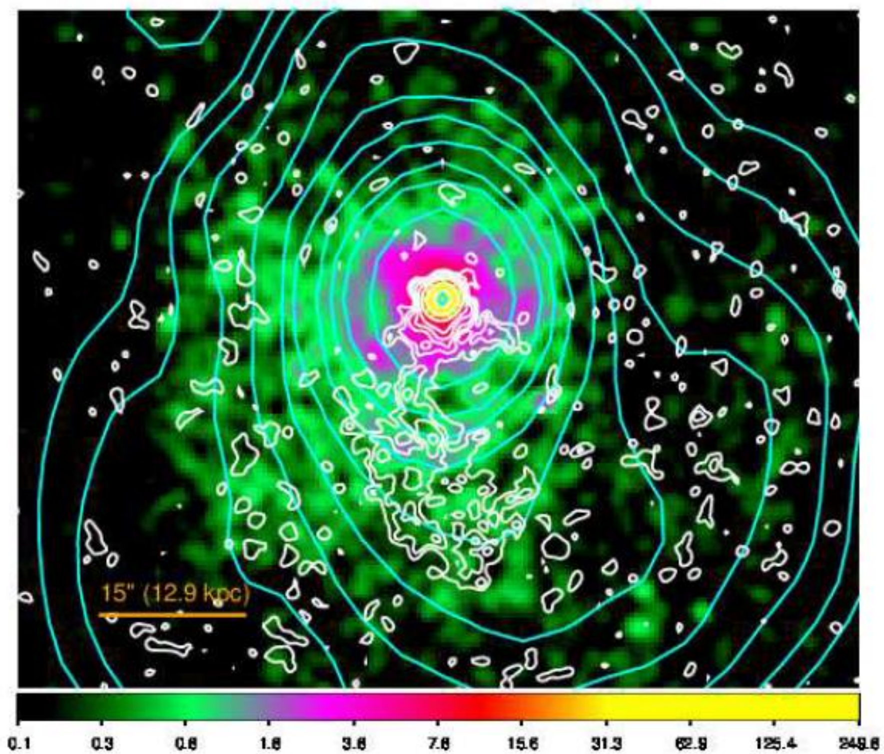


Fig. 9. Chandra soft (0.5-2 keV) X-ray image from (Veilleux et al. 2014) with overlaid contours of the VLA and WSRT continuum images. The X-ray image has been smoothed by a 3 pixel Gaussian to best match the VLA beam. Contours as in Figs 6 and 3.

(Rupke et al. 2002, 2005; Lehnert et al. 2011; Rupke & Veilleux 2013a; Cazzoli et al. 2016).

- Сравнение с Na I outflow:
- The column density of the HI in our data (ranging from 5 to 15×1021 cm−2 for *T*spin= 1000 K) is also consistent with the column density derived for the Na I (7.5 × 1021 cm−2).
- We conclude that Na I and HI are likely part of the same outflow, where the HI traces the inner regions - where the Na I outflow cannot be traced because the continuum is completely dominated by the quasar light, while the Na I is telling us about the larger scale - where the HI cannot be traced because no background radio continuum is present.

Главный вывод

- Мы наблюдаем мощный отток многофазного газа – от рентгеновского до CO, где HI сконцентрировано во внутренней области outflow – вместе с другими фазами холодного газа. Но атомарного газа меньше, чем молекулярного.
- Джет не обнаружен, и его роль в любом случае не является определяющей в энергетике потока газа.