Ghost in the Shell: Evidence for Past AGN Activities in NGC 5195 from a Newly Discovered large-scale Ionized Structure

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ABSTRACT

The early-type galaxy NGC 5195 (alternatively known as M51b) possesses extended gas features detected in multi-wavelength, postulated to be associated with previous activities of the central supermassive black hole (SMBH). Using integral field spectroscopic observations from the Canada-France-Hawaii Telescope (CFHT)/SITELLE, we report on the discovery of a new large-scale ionized gas structure traced by [O III], [N II], and Hα line emission, extending to ~ 10 kpc from the nucleus of NGC 5195. Its bipolar morphology, emission line ratio diagnostics, and comparison with the X-ray image from *Chandra* and low-frequency radio data from *LOFAR* all indicate that it is likely an outflow inflated by a past episode of elevated active galactic nucleus (AGN) activity. Assuming the ionized gas is outflowing from the central region of NGC 5195, the estimated mass and energy outflow rates are $\dot{M}_{\rm out} = 3.5$–$27.9\,{\rm M_\odot\,yr^{-1}}$ and $\dot{E}_{\rm out} = 0.98$–$7.9 \times 10^{40}\,{\rm erg\,s^{-1}}$, respectively, which cannot be provided by current star formation and the low luminosity nucleus. Alternatively, considering the history of gravitational interaction between the M51 pair and the presence of HI tidal tail, the northern large-scale ionized gas could very likely be associated with tidally stripped material illuminated by a luminous AGN in the past.

Keywords: Interacting galaxies(802) — LINER galaxies(925) — Interstellar medium(847) — Circumgalactic medium(1879)

1. INTRODUCTION

Galaxy interactions and mergers are thought to play an important role in triggering star formation and active galactic nuclei (AGNs) activities. Galactic outflows driven by AGNs are predicted by theoretical models and simulations during such a key stage of galaxy evolution. Unequivocally, multiphase AGN outflows on various scales have been detected in galaxies at different

The interacting system Messier 51 (M51) contains a grand design spiral galaxy NGC 5194 (M51a) and an early-type galaxy NGC 5195 (M51b). NGC 5195 is classified as different types of the galaxy, such as SB0$_1$-pec (Sandage & Tammann 1981) and I0-pec (de Vaucouleurs et al. 1991), due to its peculiar morphology that is tidally disturbed in the interaction. An SMBH with mass $M_{\rm BH} \sim 10^7\,{\rm M_\odot}$ is believed to reside in the nucleus

- An SMBH with mass MBH 10^7Ms is believed to reside in the nucleus of NGC 5195 (e.g. Schlegel et al. 2016; Rampadarath et al. 2018). According to the optical emission-line ratios, the nucleus is classied as the low ionization nuclear emission-line region (LINER) (Ho et al. 1997).
- Вблизи ядра галактики - the kpc-scale structures likely resemble a jet-inflated bubble associated with past AGN activities. Additionally, a vast H cloud 13’ (30 kpc) north of the M51 system was detected by Watkins et al. (2018), which was expected to be associated with the tidal stripping or AGN activities during the interaction.

Наблюдения

- Imaging Fourier spectrometer (IFTS) SITELLE at 3.6m CFHT.

Large field of view (FOV) 11’x11’ $arcmin^2$ and variable spectral resolution (R = 2000 to 10000)

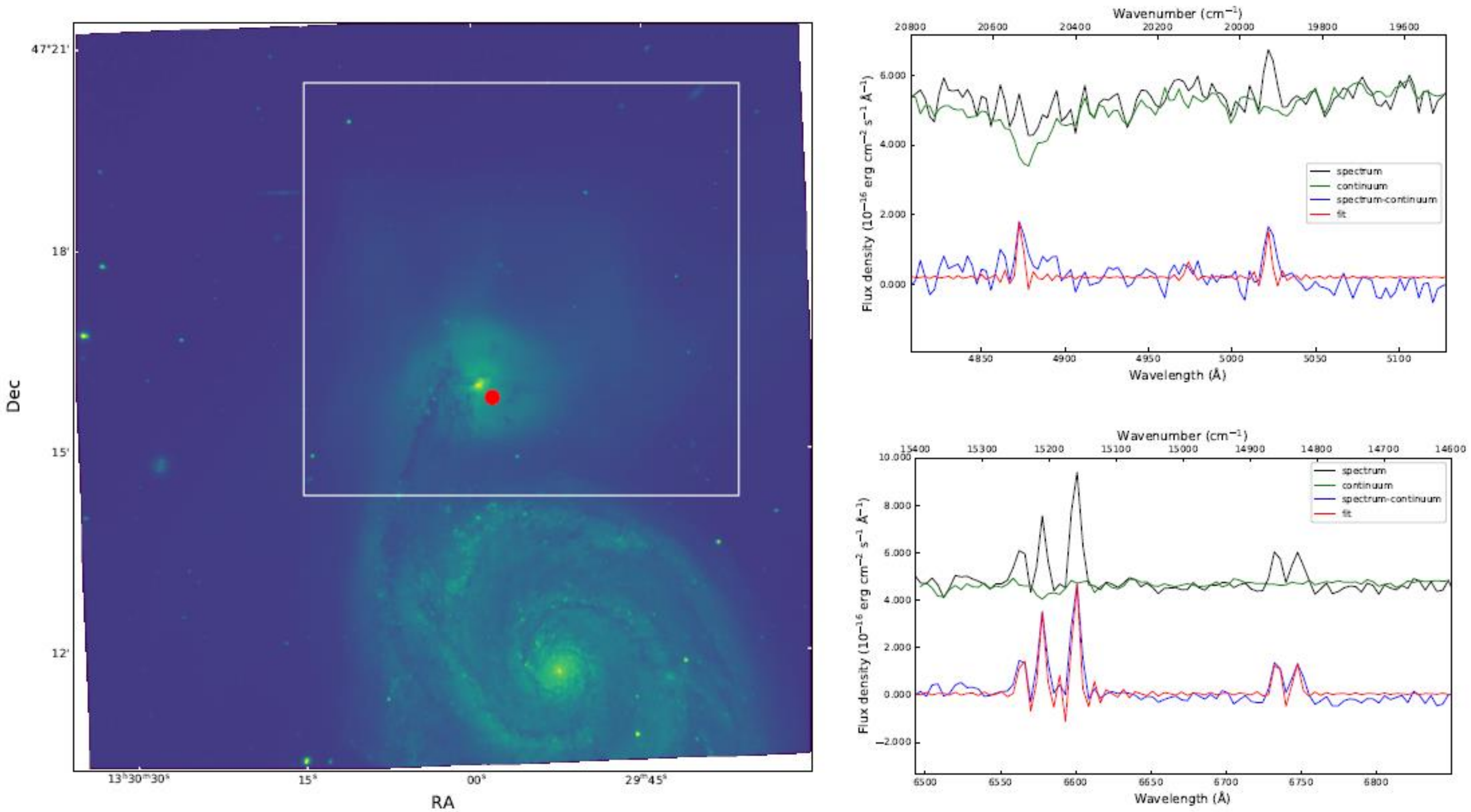


Figure 1. Left: The deep broad-band image of M51 obtained from SITELLE's SN2 datacube. The large spiral galaxy in the south is the NGC 5194 and the NGC 5195 is the smaller one above the NGC 5194. The white box denotes the region for fitting and analysis. North is to the top, and east to the left. Top right: A spectrum (black) with the continuum template (green), emission-line residual (blue), and fitting model (red) extracted from the red circle region in the left panel of the SN2 datacube. Bottom right: Same as the top right but extracted from the SN3 datacube.

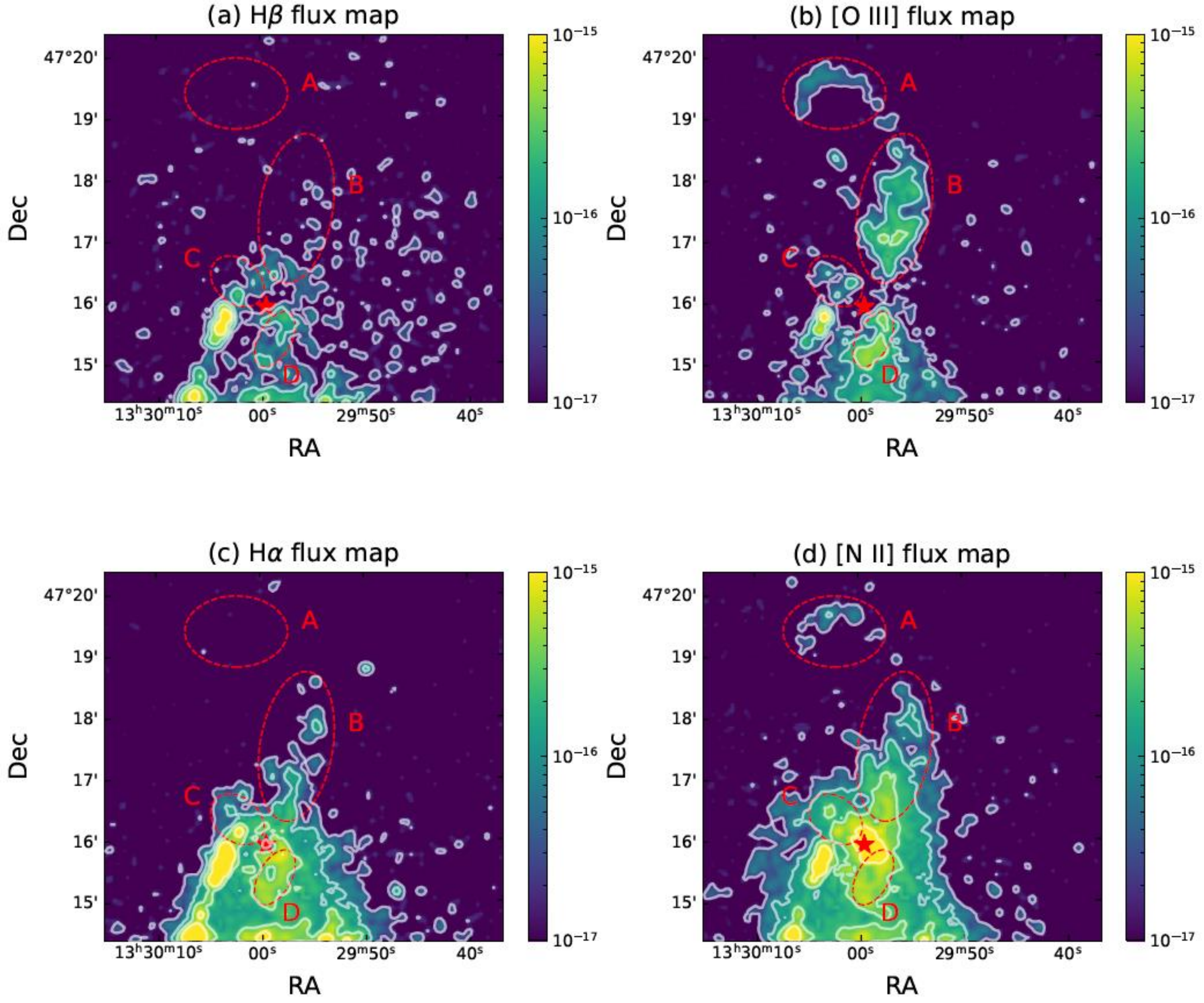


Figure 2. (a): 10×10 binned and smoothed (Gaussian kernel with radius of 1 spaxel) flux map of Hβ emission line superposed with its flux contours. The contour levels are 2×10^{-17}, 1×10^{-16}, 3×10^{-16}, and 9×10^{-16}. The unit of the colorbar is $\mathrm{erg\,cm^{-2}\,s^{-1}}$. The spaxels with SNR$<$ 3 are rejected. (b), (c), and (d) are the same as (a) but for [O III]λ5007, Hα, and [N II]λ6583, respectively. The red star marks the NGC 5195 nucleus. Four red dashed elliptical regions are labeled as A, B, C, and D, respectively.

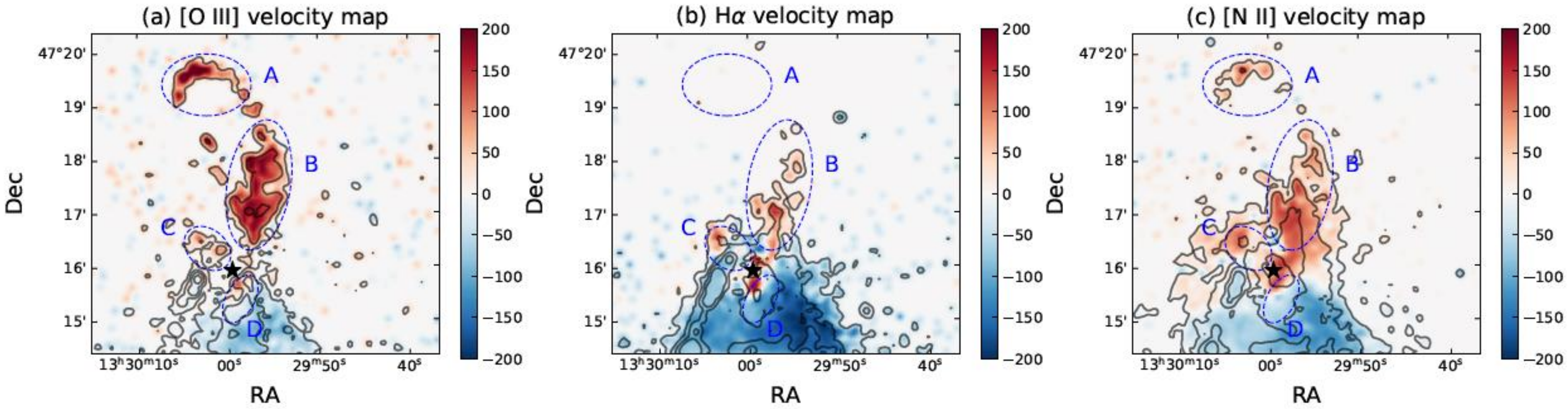


Figure 3. (a): 10 × 10 binned and smoothed (Gaussian kernel with a radius of 1 spaxel) velocity map of [O III]λ5007 superposed with the flux contours (same as contours in Figure 2). (b) and (c) are the same as (a) but for Hα and [N II]λ6583, respectively. The black star marks the position of the NGC 5195 nucleus and the four dashed regions are the same as those in Figure 2.

- The large ionized gas structure (regions A and B) is coincident with a part of a giant tidal tail traced by HI emission extending from NGC 5195 to the north.
- Considering the velocity of the corresponding HI tidal feature is about 30-90kms-1 (Rots et al. 1990), which is several times lower than the median velocity (170-270kms-1) of the northern [O iii] structure, the ionized gas feature may be a shocked by an active AGN.

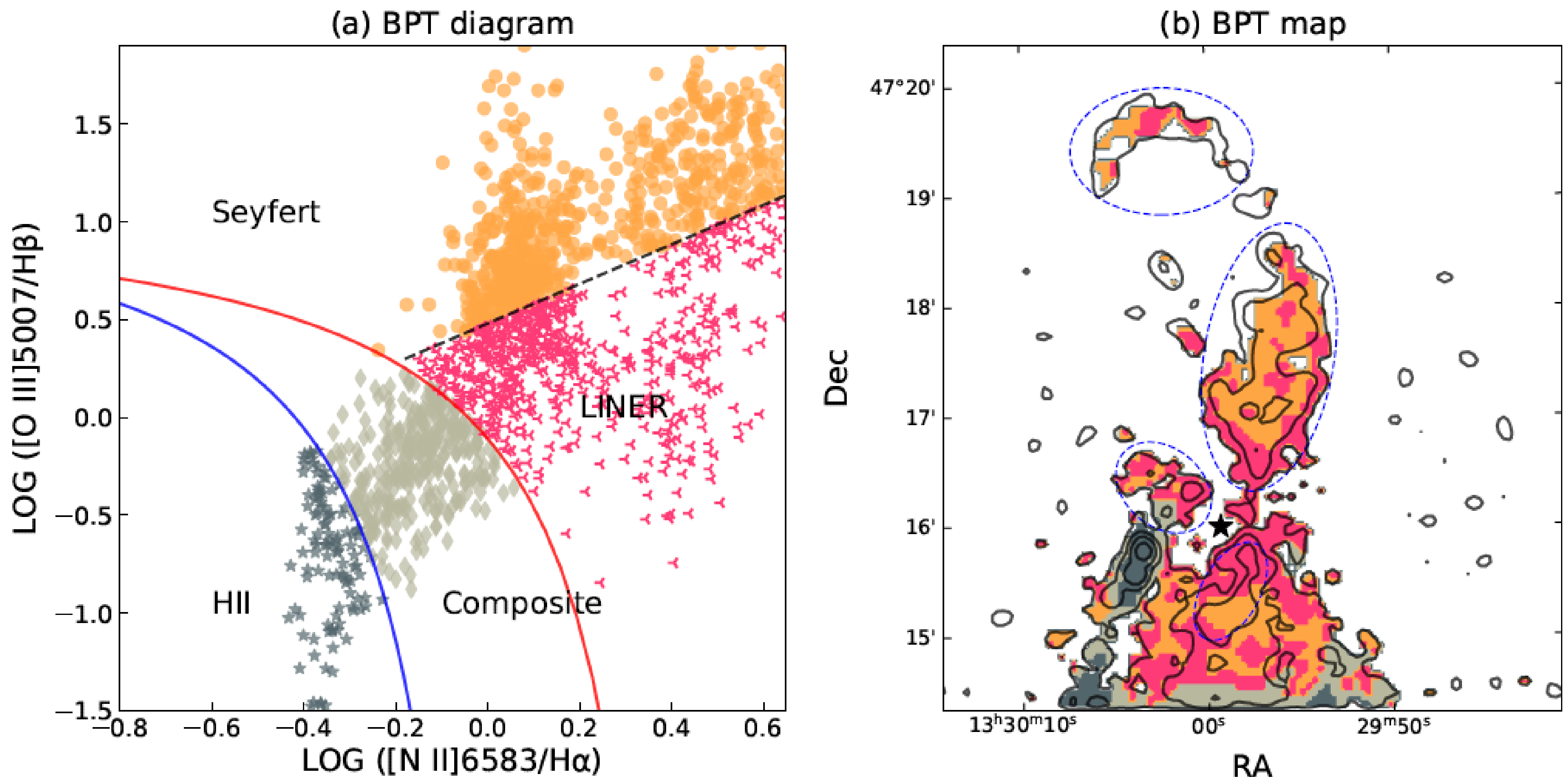
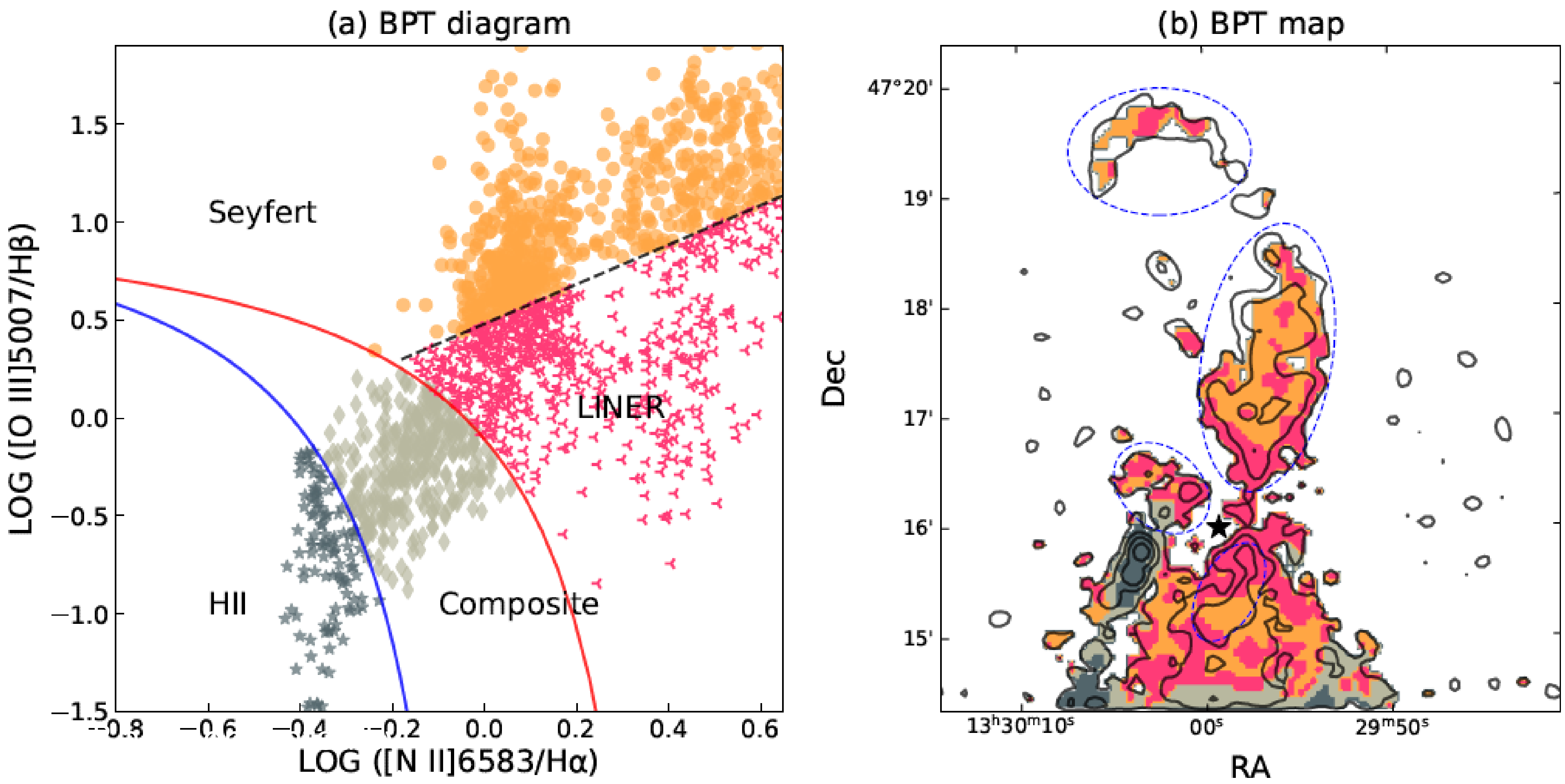


Figure 4. (a): The BPT diagnostic diagram. The blue solid line is the classification boundary in Kauffmann et al. (2003) for finding AGN. The red solid line shows the theoretical upper limit for star-forming galaxies (Kewley et al. 2001), which separates the composite emission and AGN/LINER. The dashed line (Cid Fernandes et al. 2010) shows the division between AGN and LINER. (b): Spatially resolved BPT map. The colors denote different ionization mechanisms in (a).



Region A and B are dominated by AGN photoionization, only the edges of region B are classified as LINER. In region D, the LINER dominates the area near the nucleus, while the AGN becomes the main source of ionization with the increasing distance to the nucleus.

5194, is dominated by regions classied as HII and com-

Би-полярный выброс?

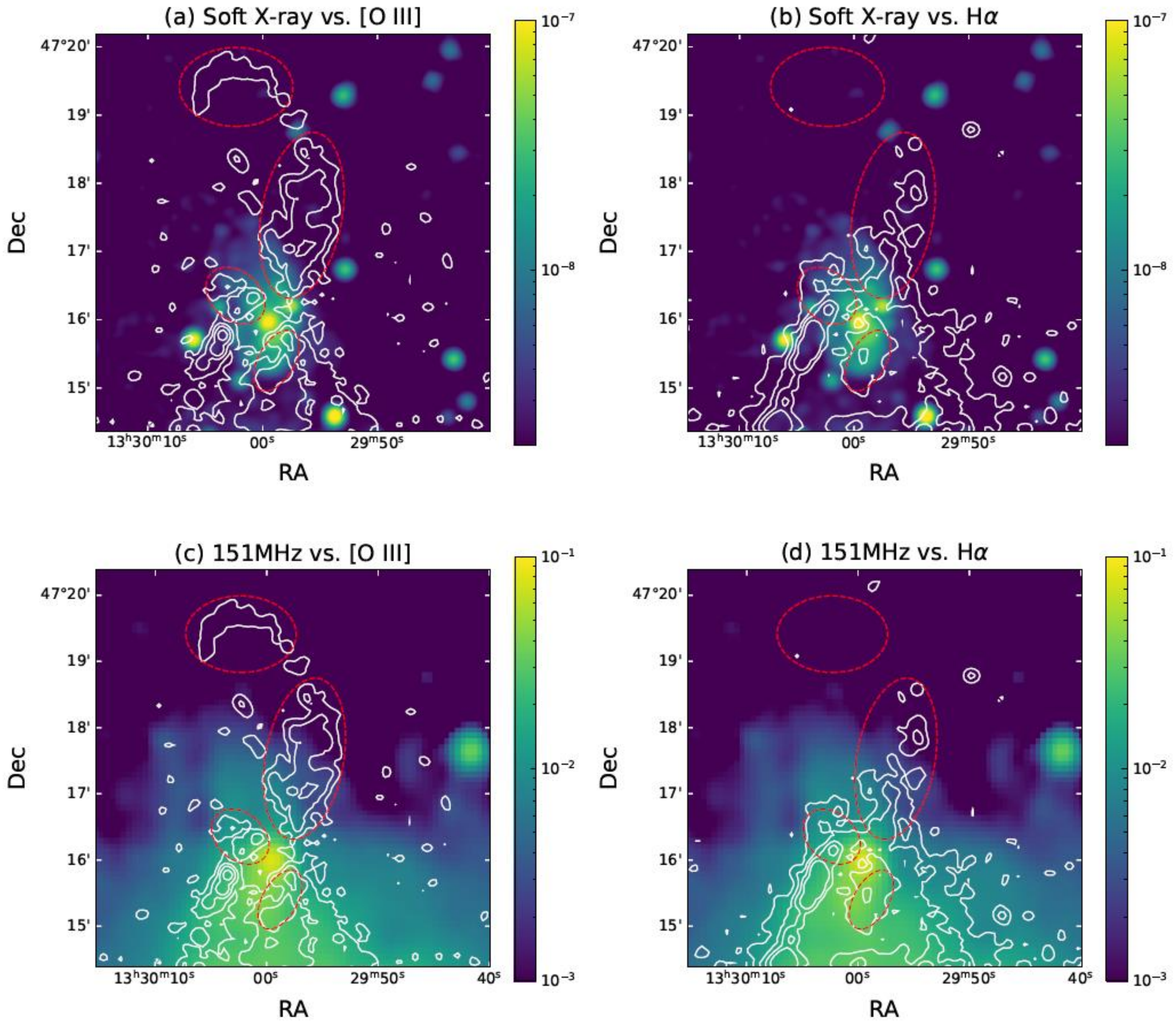


Figure 5. (a): *Chandra* soft X-ray (0.4–2.0 keV) image superposed with the contours of [O III]λ5007 flux. The unit of the colorbar is counts $cm^{-2}\,s^{-1}$. (b): Same as (a) but superposed with the contours of Hα emission. (c): LOFAR 151 MHz image (Mulcahy et al. 2014) superposed with the contours of [O III]λ5007 flux. The unit of the colorbar is Jy/beam. (d): Same as (c) but superposed with the contours of Hα emission. The red dashed elliptical regions are the same as those in Figure 2.

- Considering the current low state of the SMBH in the center of NGC 5195 and the weak [O iii] in the nuclear region, the large-scale ionized gas structure should relate to past epochs of AGN activities, which is consistent with the suggestion in previous works (Schlegel et al. 2016; Rampadarath et al. 2018).

The dynamical timescale of the ionized outflow can be estimated to be $t_{\rm dyn} \approx D_{\rm out}/v_{\rm out} = 30\,{\rm Myr}$, where $D_{\rm out} \sim 10\,{\rm kpc}$ denotes the distance away from the nucleus and $v_{\rm out} \sim 300\,{\rm km\,s^{-1}}$ is the outflow velocity.

- Динамическое время примерно соответствует времени после максимального сближения двух галактик.
- Аналогия с объектом Hannys Voorwerp

$$M_{\rm gas} = 4 \times 10^8 (\frac{L_{\rm [OIII]}}{10^{44}\ {\rm erg\ s^{-1}}})(\frac{100\ {\rm cm^{-3}}}{n_e})\ {\rm M_\odot},$$

$$n_{\rm e} \approx 0.01\,{\rm cm^{-3}}$$

$$\dot{M}_{\rm out} = 3.5\,{\rm M_\odot\,yr^{-1}}\ \text{and}\ \dot{E}_{\rm out} = 9.8 \times 10^{40}\,{\rm erg\,s^{-1}}.$$

Comparing with the kinetic power resulting from the stellar winds and SNe (Rampadarath et al. 2018) given the current SFR $\approx 0.1\,\mathrm{M_\odot\,yr^{-1}}$ of NGC 5195 (Alatalo et al. 2016), even the lower limit of the energy outflow rate is larger by a factor of two to three, which imply that the current star formation process cannot drive the ionized outflow. A starburst that occurred 370–480 Myr ago had been suggested by Mentuch Cooper et al. (2012), while this is not consistent with the timescale of the ionized outflow ($t_{\mathrm{dyn}} \approx 30\,\mathrm{Myr}$).