MAUVE: A 6 kpc bipolar outflow launched from NGC 4383, one of the most H I-rich galaxies in the Virgo cluster

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ABSTRACT

Stellar feedback-driven outflows are important regulators of the gas-star formation cycle. However, resolving outflow physics requires high resolution observations that can only be achieved in very nearby galaxies, making suitable targets rare. We present the first results from the new VLT/MUSE large program MAUVE (MUSE and ALMA Unveiling the Virgo Environment), which aims to understand the gas-star formation cycle within the context of the Virgo cluster environment. Outflows are a key part of this cycle, and we focus on the peculiar galaxy NGC 4383, which hosts a ∼ 6 kpc bipolar outflow fuelled by one of Virgo's most H I-rich discs. The spectacular MUSE data reveal the clumpy structure and complex kinematics of the ionised gas in this M82-like outflow at 100 pc resolution. Using the ionised gas geometry and kinematics we constrain the opening half-angle to $\theta = 25 - 35°$, while the average outflow velocity is $\sim 210\,\mathrm{km\,s^{-1}}$. The emission line ratios reveal an ionisation structure where photoionisation is the dominant excitation process. The outflowing gas shows a marginally elevated gas-phase oxygen abundance compared to the disc but is lower than the central starburst, highlighting the contribution of mixing between the ejected and entrained gas. Making some assumptions about the outflow geometry, we estimate an integrated mass outflow-rate of $\sim 1.8\,\mathrm{M_\odot\,yr^{-1}}$ and a corresponding mass-loading factor in the range 1.7-2.3. NGC 4383 is a useful addition to the few nearby examples of well-resolved outflows, and will provide a useful baseline for quantifying the role of outflows within the Virgo cluster.

Key words: galaxies: starburst – galaxies: star formation – galaxies: ISM

In the extreme cases of galaxies with intense central bursts of star formation, the resulting feedback can drive large outflows of metal-enriched gas from the centres of galaxies far into their CGM (e.g., Heckman et al. 2000; Tremonti et al. 2004; Borthakur et al. 2013; Chisholm et al. 2018; Proux et al. 2020).
Most of the outflow energy is contained within a hot ($T > 10^6$ K) phase, while the mass is carried by colder ($T \lesssim 10^4$ K) neutral atomic and molecular gas entrained in the outflow.

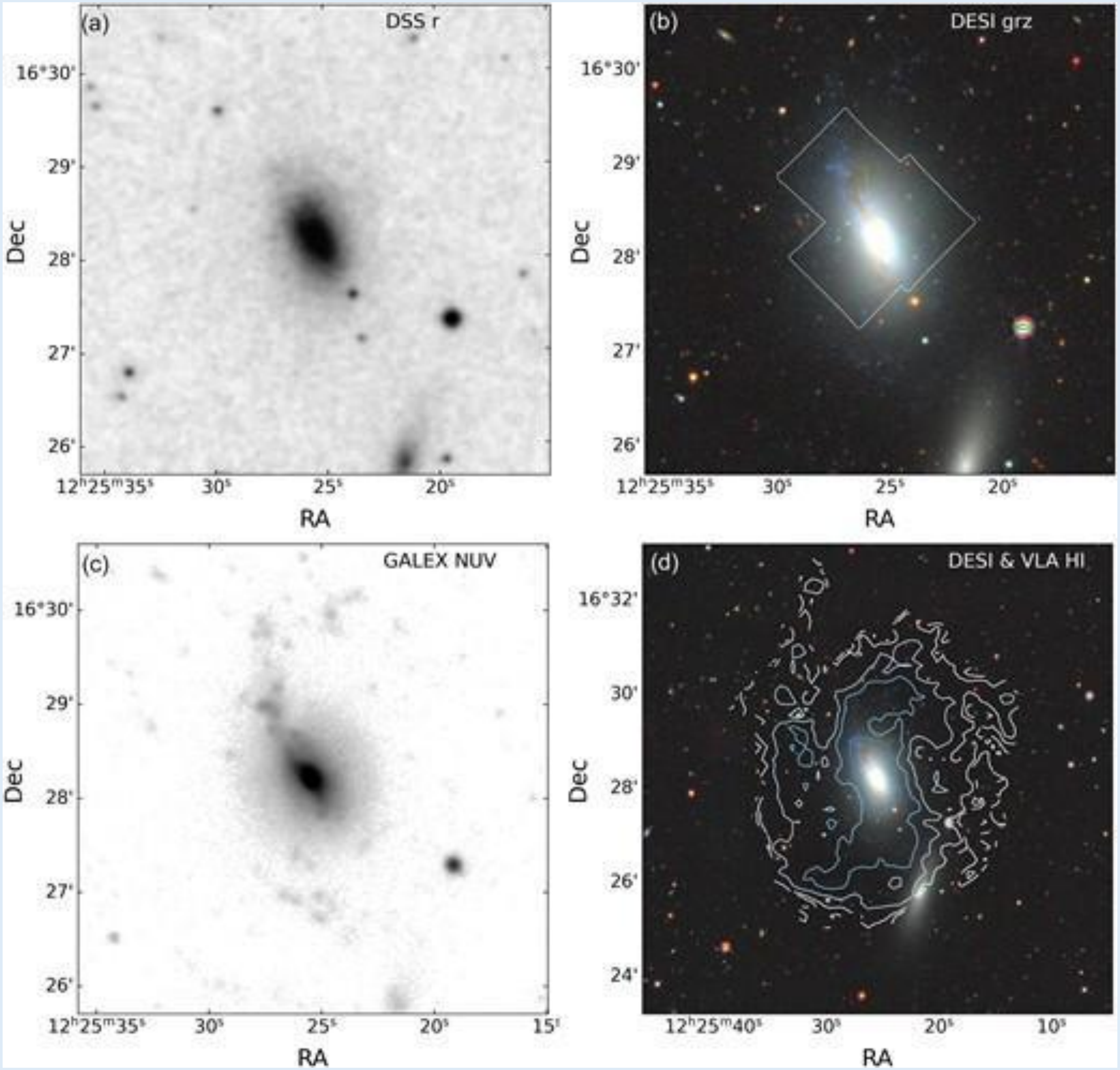
- Исследование spatially resolved nature of outflows до сих пор ограничено всего несколькими системами. Наиболее подробно – M82.
- In this paper, **we present the first results of the MUSE and ALMA Unveiling the Virgo Environment (MAUVE) survey, a new ESO large program targeting Virgo cluster galaxies with the Multi Unit Spectroscopic Explorer (MUSE, Bacon et al. 2010) on the VLT.**

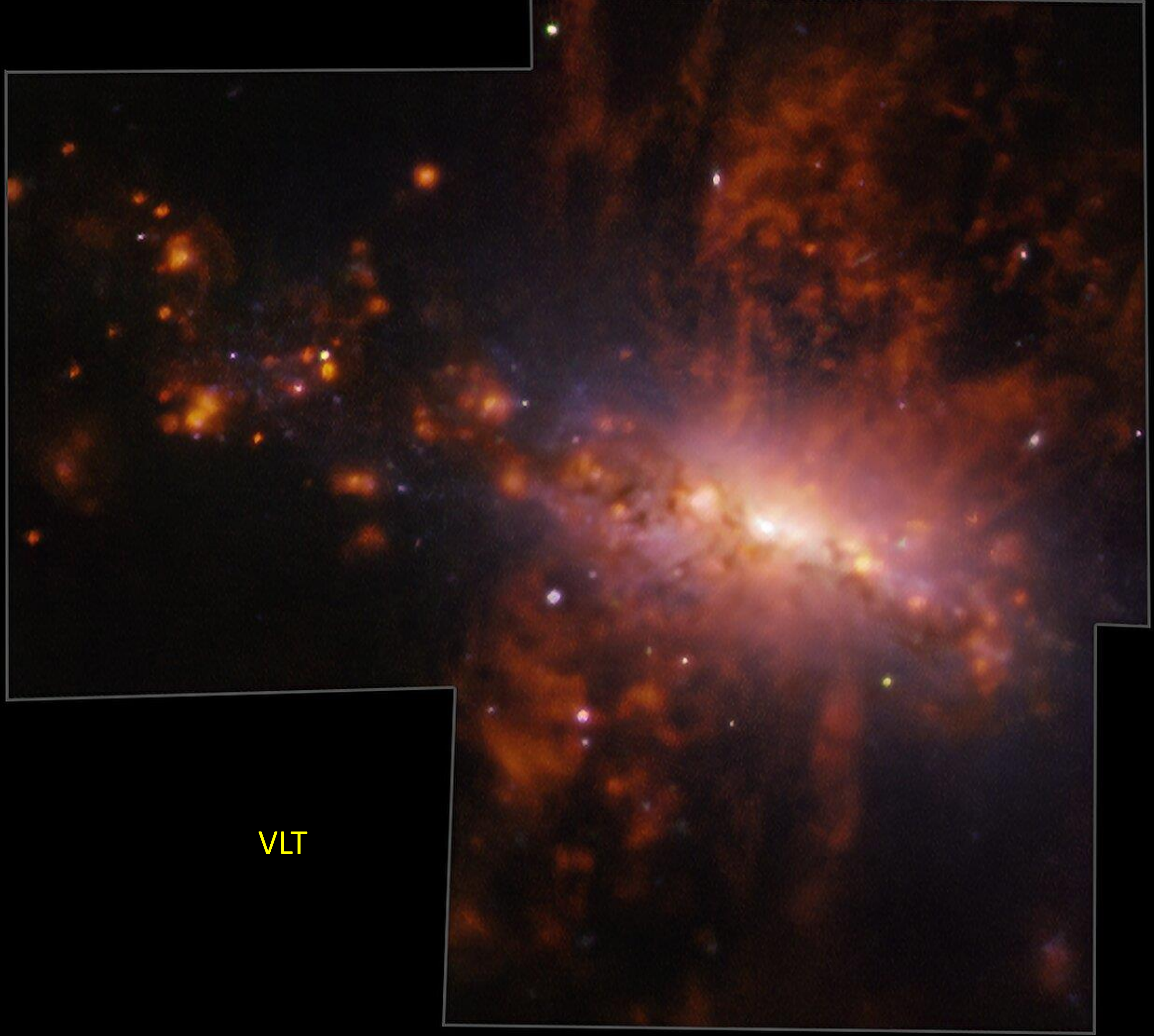
NGC4383 is an intermediate-mass galaxy ($\log(M_\star/M_\odot) = 9.44$, in the Virgo cluster, located $\sim$ 1.25 Mpc North-East of M 87, just inside the R200 radius of Virgo. Balzano (1983) first identified the central starburst. The SFR estimated from UV+IR emission is $1.02 M_\odot\ yr^{-1}$.

HI прослеживается

до 4.2 R25.

Log MHI = 9.46





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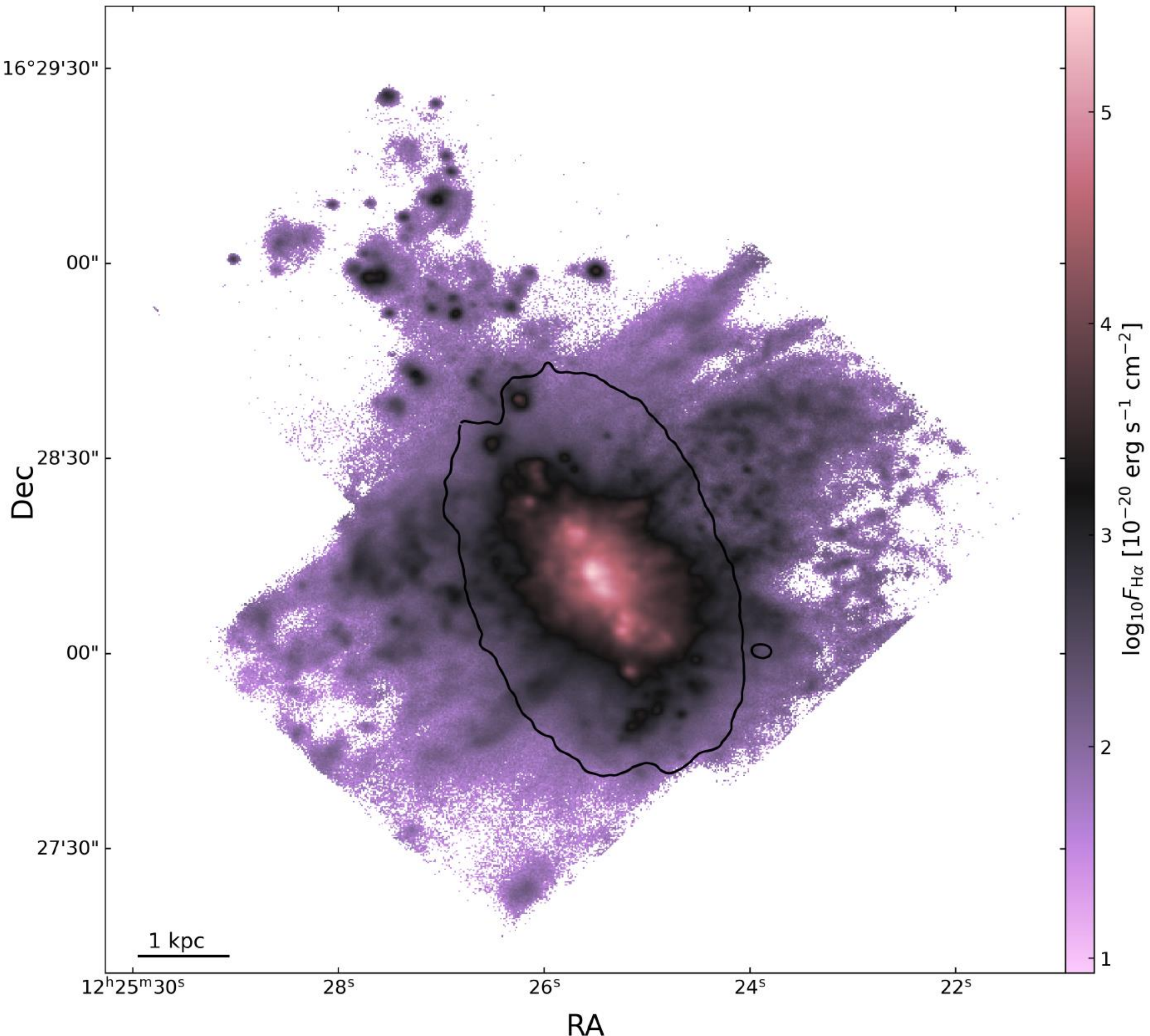
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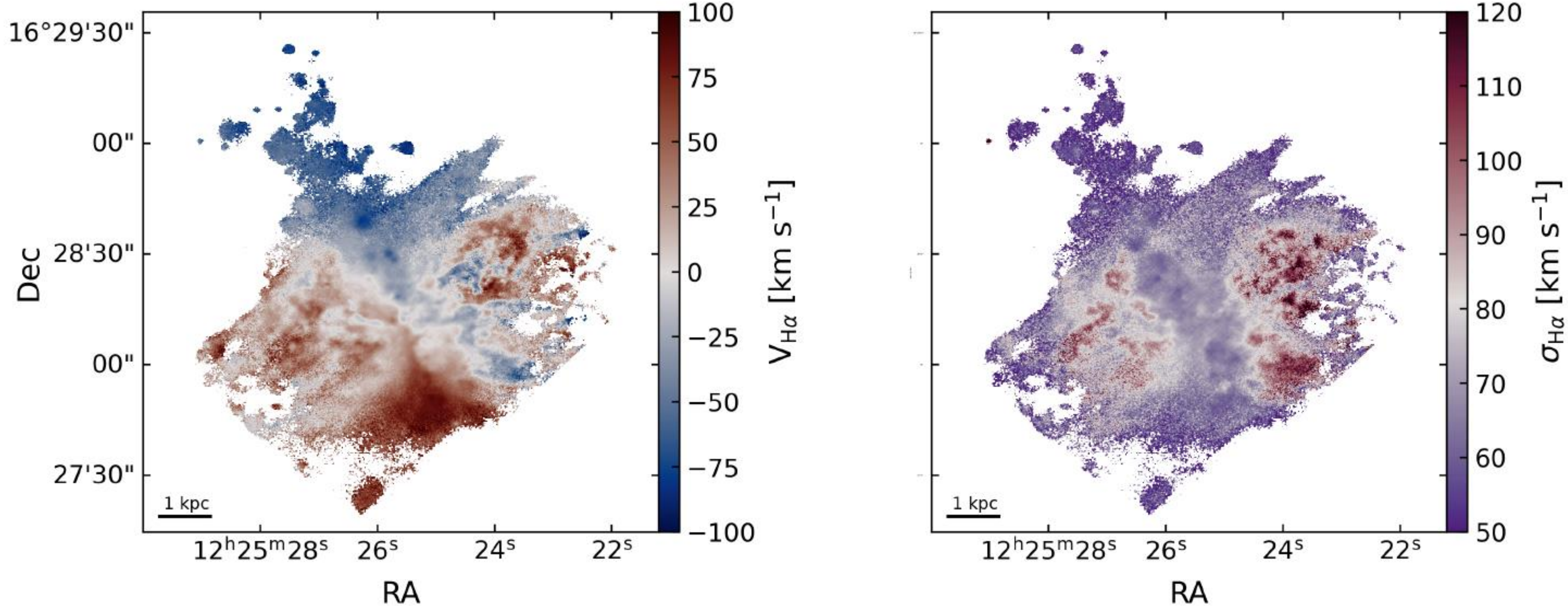
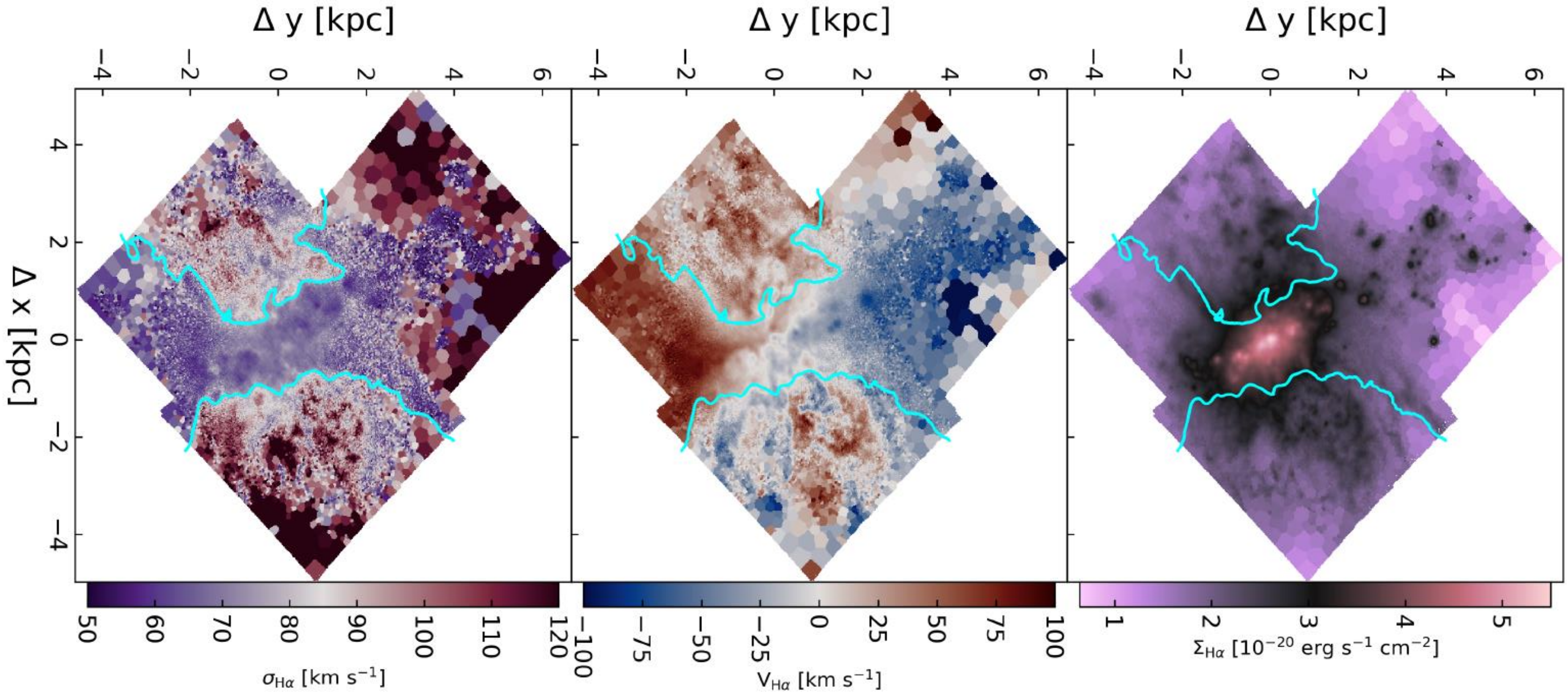


Figure 2. Derived Hα emission line properties. The main panel shows our integrated Hα flux map in units of 10^{-20}erg s^{-1} cm^{-2}, with the DESI r-band 25$^{\text{th}}$ mag arcsec^{-2} isophote overlaid in black. The bottom two panels show the Hα flux-weighted first moment (line-of-sight velocity, left) and second moment (velocity dispersion, right). All panels highlight the complex and clumpy distribution and motions of the Hα gas in the galaxy. The top panel shows chimneys and shells associated with the bipolar outflow, while the bottom two panels show the multiple line-of-sight velocity components within outflow-dominated spaxels outside the galaxy's major axis.

- Using the kinematics of the line-splitting, we estimated an intrinsic (i.e., corrected for inclination) outflow velocity in the range v_{out} = 184 − 246 km s−1 (average 210 km s−1), with no clear trend with increasing height above the disc



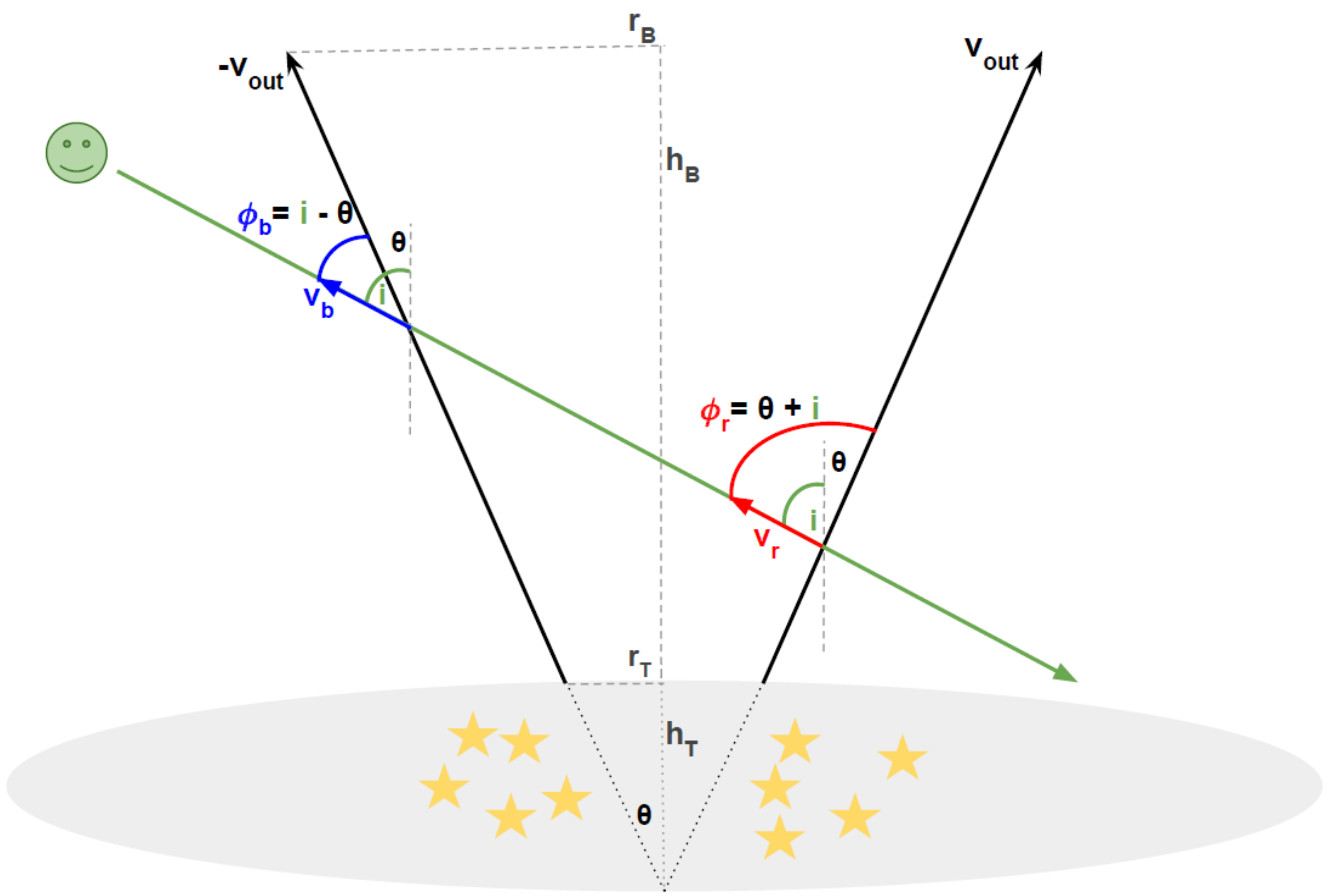


Figure A1. Adopted geometry for the NGC 4383 outflow. Lower case subscripts (r and b) denote red- and blue-shifted velocity components. Upper case subscripts are used to refer to the spatial geometry, with ‘B’ and ‘T’ indicating the base and the removed top of the frustum, respectively.

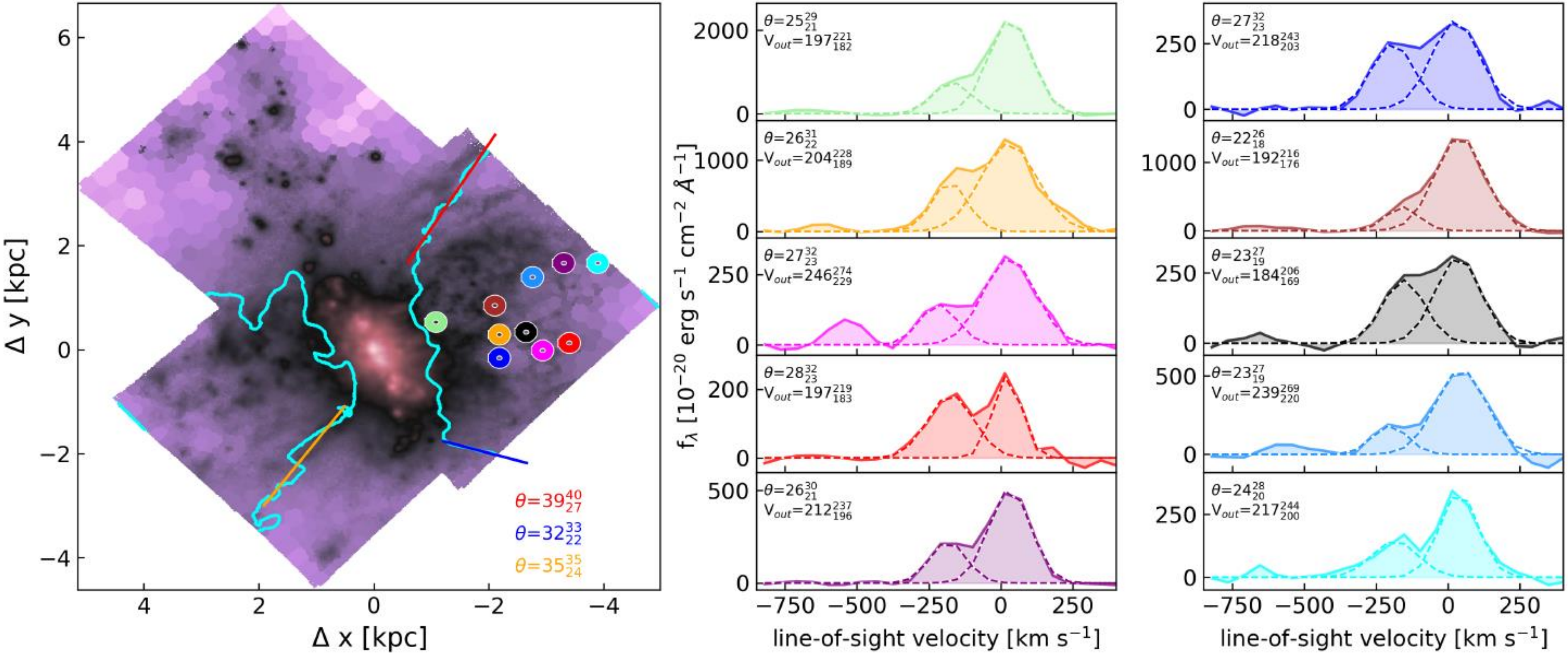
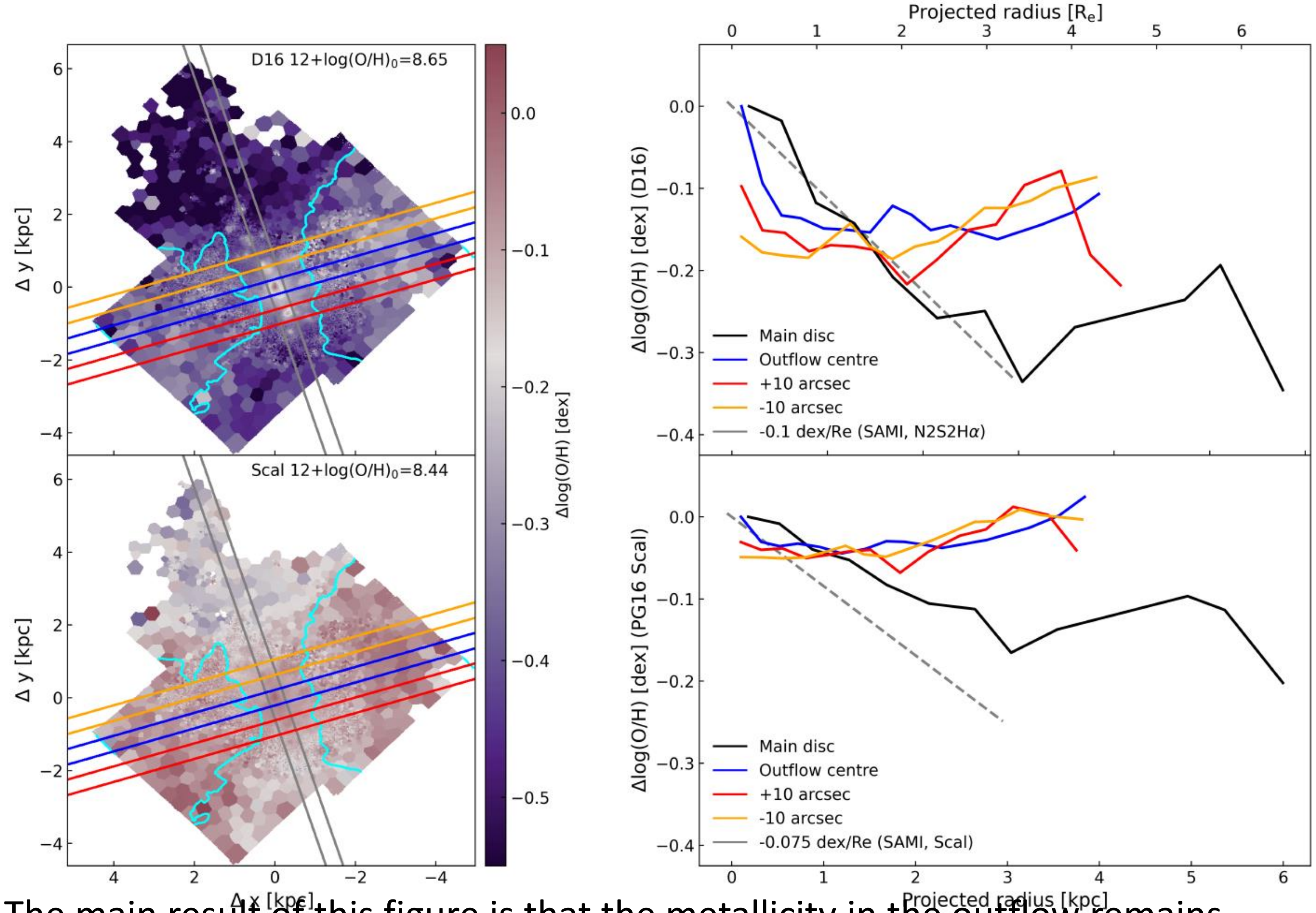
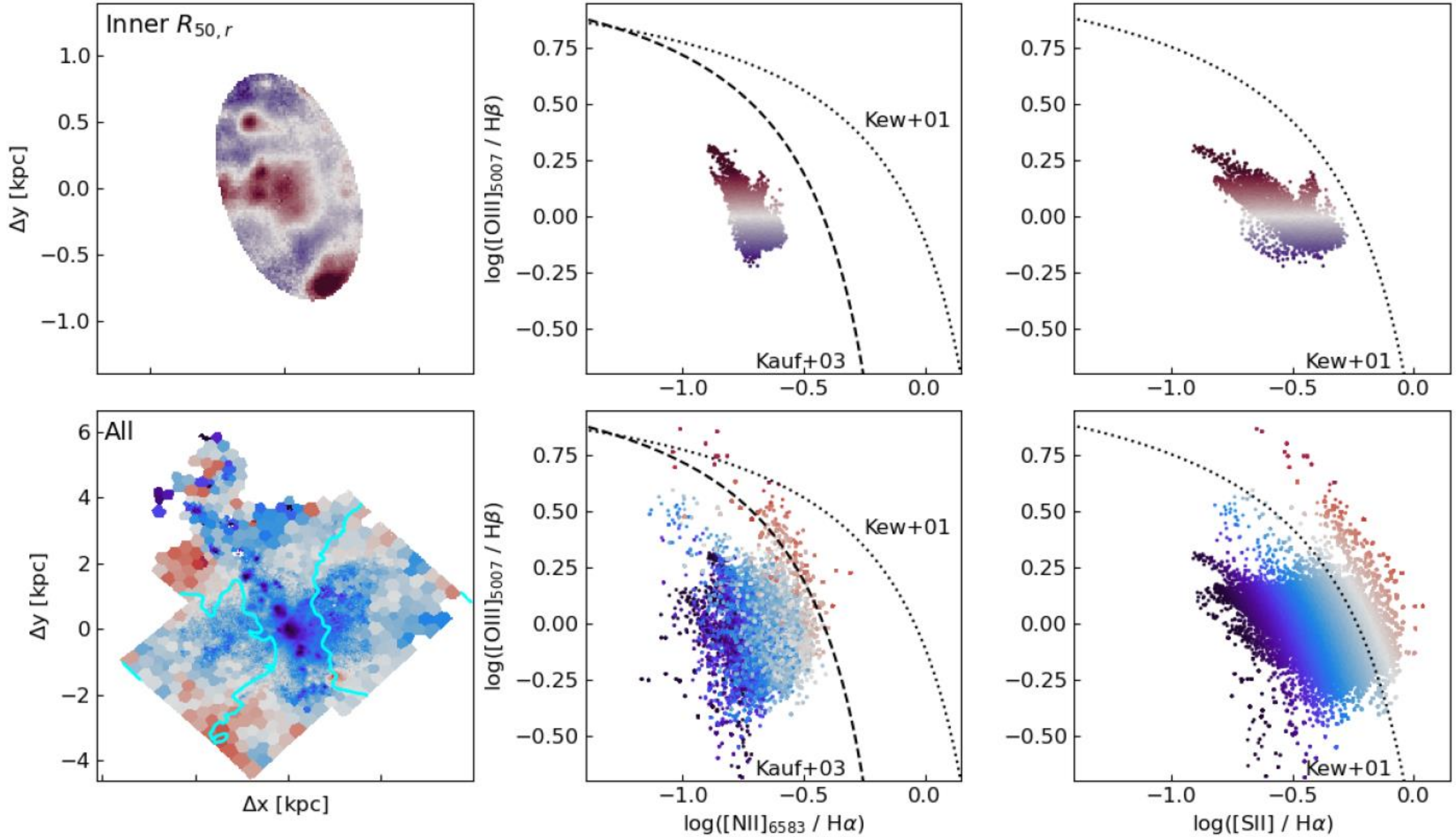


Figure 5. Outflow opening half-angle (θ) measurements. Left: Contours defining the outflow-dominated emission overlaid on the binned Hα flux map. Red, blue, and orange lines show the linear fits used to estimate θ. The inclination-corrected estimates for θ are given in the bottom right corner in their corresponding colour, all of which agree well. Right: Spectra that exhibit line splitting, extracted from the like-coloured apertures (enlarged by 3×) in the NW region of the outflow in the left panel. Dashed lines represent the two Gaussian fits to each spectrum, and the derived outflow velocity and opening half-angle are quoted in the top left corner of each panel. In both panels, variations in θ and $v_{\rm out}$ due to a change in inclination of ±5° are given as superscripts and subscripts Across all methods, θ is constrained to $22° - 39°$, with outflow velocities in the range $184 - 246\,{\rm km\,s^{-1}}$.



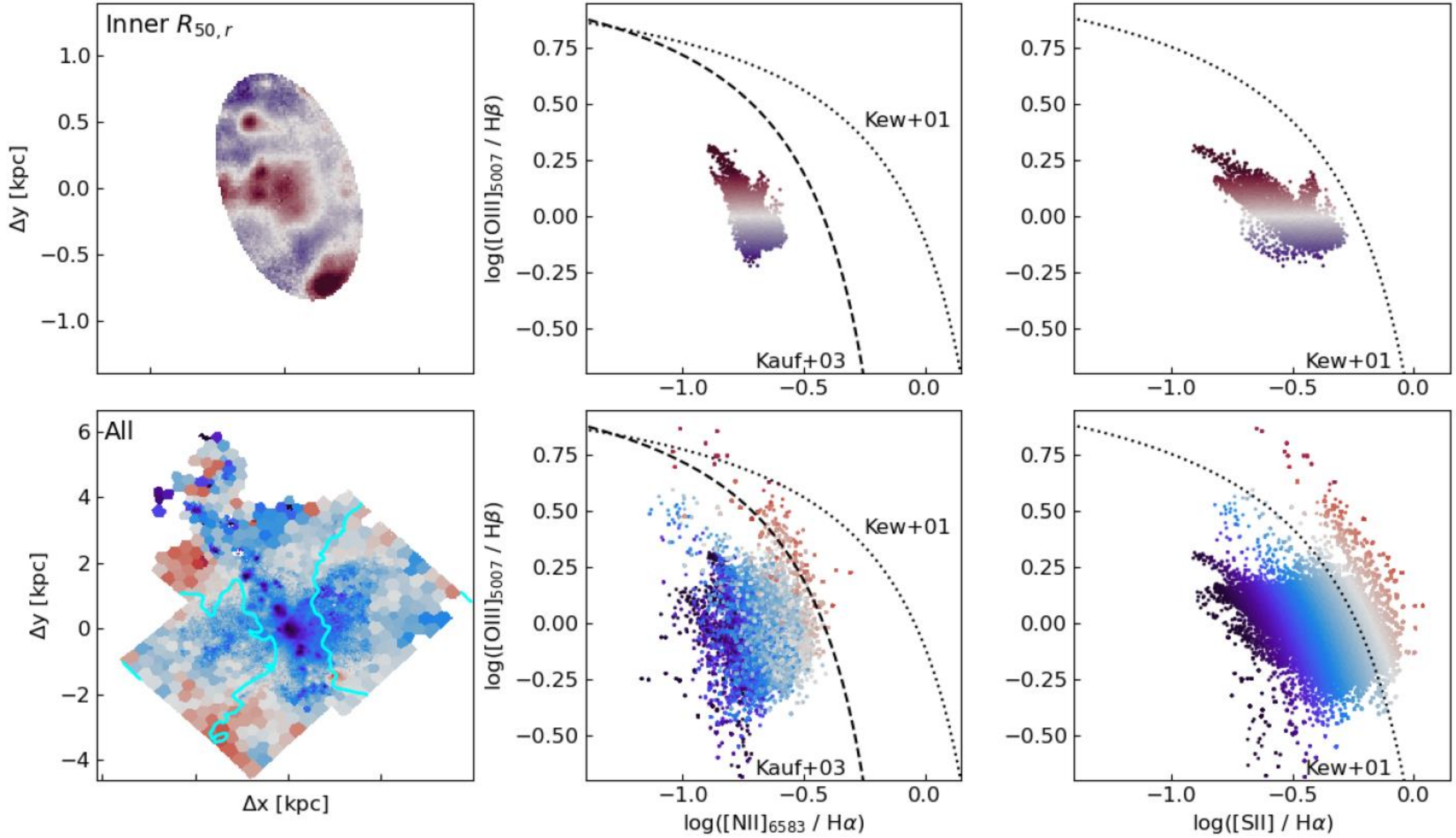
The main result of this figure is that the metallicity in the outflow remains elevated compared to the disc but is not more metal rich than the galaxy's centre.

Figure 7. Metallicity gradients in the disc and outflow. The top two panels use the Dopita et al. (2016) metallicity calibration, while the bottom two use the Pilyugin & Grebel (2016) 'Scal' calibration. Left: spatially resolved $12 + \log(O/H)$ map of NGC 4383, normalised to the central metallicity, quoted in each panel's top right. Cyan contours highlight the outflow-dominated regions. Right: radial metallicity gradients aligned with the major axis (black line, grey slit in left panel), the minor axis (blue) tracing the outflow centre, the outflow centre and ±10 arcsec (red and orange lines and slits). All radial profiles are normalised to the central metallicity, and we show the typical radial gradient for a $\log(M_\star/\mathrm{M}_\odot) \approx 9.5$ galaxy from Poetrodjojo et al. (2021) for each calibration with a grey line. The main result of this figure is that the metallicity in the outflow remains elevated compared to the disc but is not more metal rich than the galaxy's centre.



The core of the outflow in NGC4383 is ionised by star formation, while the contribution from shocked gas becomes more important outside the core as the spaxel colours transition from blue through to white.

Figure 6. Spatially resolved BPT diagrams. The left column shows the spatial distribution of spaxels in the galaxy centre (within 1 $R_{50,r}$, top row), and the entire galaxy (bottom row). The middle and right columns show [NII]$_{6583}$/Hα and [SII]/Hα vs [OIII]$_{5007}$/Hβ BPT diagrams for the spaxels in each selection, respectively. In the top row, spaxels are coloured by their [OIII]$_{5007}$/Hβ ratio, while the bottom row is coloured by their [SII]/Hα distance from the Kewley et al. (2001) demarcation line. The galaxy's centre shows a clear contrast between high-ionisation H II regions and the more diffuse emission. The core of the outflow in NGC 4383 is ionised by star formation, while the contribution from shocked gas becomes more important outside the core as the spaxel colours transition from blue through to white.



Области ударных волн – по краям конуса, а в основном - фотоионизация

Figure 6. Spatially resolved BPT diagrams. The left column shows the spatial distribution of spaxels in the galaxy centre (within 1 $R_{50,r}$, top row), and the entire galaxy (bottom row). The middle and right columns show $[NII]_{6583}/H\alpha$ and $[SII]/H\alpha$ vs $[OIII]_{5007}/H\beta$ BPT diagrams for the spaxels in each selection, respectively. In the top row, spaxels are coloured by their $[OIII]_{5007}/H\beta$ ratio, while the bottom row is coloured by their $[SII]/H\alpha$ distance from the Kewley et al. (2001) demarcation line. The galaxy's centre shows a clear contrast between high-ionisation H II regions and the more diffuse emission. The core of the outflow in NGC 4383 is ionised by star formation, while the contribution from shocked gas becomes more important outside the core as the spaxel colours transition from blue through to white.

Сравнение с M82:

- Наличие гигантского вращающегося диска HI
- Нет явных признаков сильного взаимодействия с соседней галактикой.
- Ионизационные структуры конуса сходны с M82
- Как и в M82, the outflow is metal-enriched but not more so than the central star forming region or the disc.Как

Основные выводы

- Выброс газа прослеживается ло расстояния 5.8 кпс от диска.
- The outflow emission has an average velocity of $v$out $\sim$ 210 km s−1, with a maximum outflow velocity of $v$max $\sim$ 300 km s−1.
- The line ratios gradually get closer to a shock-ionised origin towards the edge of the cone.
- The mass outflow rate of the ionised gas integrated over the outflow-dominated regions is estimated to be 1.9M$\odot$ yr−1, corresponding to a mass-loading factor of ηM $\sim$ 1.7 − 2.3.
- Mass outflow rate and loading factor are within the ranges expected from literature. However, these are definitely lower limits on the true mass outflow rate as the ionized gas phase does not trace a significant fraction of the outflowing mass. Instead, the colder, neutral gas phases entrained by the outflow carry most of the mass, for which Hi is a powerful tracer