NGC6240: extended CO structures and their association with shocked gas

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ABSTRACT

We present deep CO(1-0) observations of NGC6240 performed with the IRAM Plateau de Bure Interferometer (PdBI). NGC6240 is the prototypical example of a major galaxy merger in progress, caught at an early stage, with an extended, strongly-disturbed butterfly-like morphology and the presence of a heavily obscured active nucleus in the core of each progenitor galaxy. The CO line shows a skewed profile with very broad and asymmetric wings detected out to velocities of ~600 km/s and +800 km/s with respect to the systemic velocity. The PdBI maps reveal the existence of two prominent structures of blueshifted CO emission. One extends eastward, i.e. approximately perpendicular to the line connecting the galactic nuclei, over scales of ~7 kpc and shows velocities up to ~400 km/s. The other extends southwestward out to ~7 kpc from the nuclear region, and has a velocity of ~100 km/s with respect to the systemic. Interestingly, redshifted emission with velocities 400 to 800 km/s is detected around the two nuclei, extending in the east-west direction, and partly overlapping with the eastern blue-shifted structure, although tracing a more compact region of size ~1.7 kpc. The overlap between the southwestern CO blob and the dust lanes seen in HST images, which are interpreted as tidal tails, indicates that the molecular gas is deeply affected by galaxy interactions. The eastern blueshifted CO emission is co-spatial with an Hα filament that is associated with strong H2 and soft X-ray emission. The analysis of Chandra X-ray data provides strong evidence for shocked gas at the position of the Hα emission. Its association with outflowing molecular gas supports a scenario where the molecular gas is compressed into a shock wave that propagates eastward from the nuclei. If this is an outflow, the AGN are likely the driving force.

Key words. Galaxies: active – Galaxies: interaction – Galaxies: evolution – Galaxies: ISM – Galaxies: quasars – general

1. Introduction

The observed transformation of gas-rich star-forming galaxies into red, bulge-dominated spheroids devoid of gas, is due to several mechanisms. In massive galaxies star formation might lead to a faster gas consumption rate, compared to less massive ones (Daddi et al. 2007, Peng et al. 2010, Elbaz et al. 2011, Rodighiero et al. 2011). In addition, galaxy interactions, mergers (Sanders et al. 1988, Barnes & Hernquist 1996, Cavaliere & Vittorini 2000, Di Matteo et al. 2005), together with active galactic nuclei (AGN) and starburst feedback are expected to play a role (Silk & Rees 1999, King 2010 and references therein). Mergers can destabilize cold gas and trigger both star formation and nuclear accretion onto super-massive black holes (SMBHs), inducing AGN activity. A natural expectation of this scenario is that the early, powerful AGN phase is highly obscured by large columns of gas and dust (e.g. Fabian 1999). Once a SMBH reaches masses >10⁷–⁸ M☉, the AGN can efficiently contribute to the radiative heating of the inter stellar medium (ISM) through winds and shocks, thus inhibiting further accretion and also star-formation in the nuclear region and possibly at larger scales in the galactic disk. The radiative feedback from a luminous AGN is therefore a mechanism that could explain the low gas content of local massive galaxies and the galaxy bimodal color distribution (Kauffmann et al. 2003, Croton et al. 2006, Menci et al. 2006). This evolutionary scenario needs to be observationally confirmed. This can be achieved by observing systems during a major interaction phase, that probe both AGN and starburst-driven winds, and their interaction with the molecular gas, which represents the bulk of the gas in a galaxy.

Only recently molecular gas outflows have been discovered in both star-forming galaxies (e.g. M82, Walter et al. 2002, Arp 220, Sakamoto et al 2009) and in the hosts of powerful AGN, through the detection of both molecular absorption lines with P-Cygni profiles, and of broad molecular emission lines (Feruglio et al. 2010, Fisher et al 2010, Alatalo et al. 2011, Sturm et al. 2011, Aalto et al. 2012, Cicone et al. 2012, Maiolino et al. 2012). The inferred outflow rates show that these outflows can displace large amounts (several hundreds of solar masses per year) of molecular gas into the galactic disk, hence support-
ing AGN feedback model predictions (e.g. King 2005, 2010, Zubovas & King 2012, Lapi et al. 2005, Menci et al. 2008). In particular, strong molecular outflows have been found in several local Ultra Luminous Infrared Galaxies (ULIRGs), suggesting that they might be common in objects undergoing major mergers (Sturm et al. 2011). The "prototype" of this class of objects is Mrk 231, in which we indeed discovered a massive molecular outflow extended on scales of ~1 kpc in the host galaxy disk (Feruglio et al. 2010). Mrk231 is known to be in a late merger state (Sanders et al. 1988, Davies et al. 2005), and shows a compact molecular disk (Carilli et al. 1998).

In the framework of the exploration of massive molecular outflows in nearby ULIRGs and LIRGs, we present in this work our millimeter observations of the nearby merger NGC6240. This is a prototypical galaxy undergoing transformations. Thanks to its close distance (z=0.024), this system offers the opportunity to investigate in detail the distribution and dynamics of the molecular gas during a merger event, which represents the key process in hierarchical models of galaxy formation and evolution. It is a massive object, resulting from the merger of two gas rich spirals. The nuclei, separated by ~ 2'', in approximately the north-south direction, are located in the central region of the system, probably the remnants of the bulges of the progenitor galaxies, since the majority of the nuclear stellar luminosity is provided by stars predating the merger (Engel et al. 2010). Each nucleus hosts an AGN (Komossa et al. 2003). At least one of the two gas rich spirals. The nuclei, separated by ~ 2'', in approximately the north-south direction, are located in the central region of the system, probably the remnants of the bulges of the progenitor galaxies, since the majority of the nuclear stellar luminosity is provided by stars predating the merger (Engel et al. 2010). Each nucleus hosts an AGN (Komossa et al. 2003). At least one of the AGN is highly obscured by a hydrogen column density of $N_H > 10^{23}$ cm$^{-2}$ (Compton-thick), and has an intrinsic luminosity L(2-10 keV)$ > 10^{44}$ erg s$^{-1}$ (Vignati et al. 1999). The mass of the SMBH powering this AGN likely exceeds $10^7$ M$_\odot$ (Engel et al. 2010). The system is in an early, short-lived phase of merging, likely between the first encounter and the final coalescence, and shows a compact molecular disk (Carilli et al. 1998).

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The nebula is interpreted as evidence of a super-wind shock-heating the ambient ISM. The emission line filaments and bubbles appear to trace a bipolar outflow pattern, aligned east-westward, extending up to 15-20 arcsec (7-10 kpc) from the nuclear region perpendicular to the wide dust lane seen in the HST Hø images (Gerssen et al. 2004). The nebula is interpreted as evidence of a super-wind shock-heating the ambient ISM. The emission line filaments and bubbles appear to trace a bipolar outflow pattern, aligned east-westward, extending up to 15-20 arcsec (7-10 kpc) from the nuclear region perpendicular to the wide dust lane seen in the HST Hø images (Gerssen et al. 2004), and to the line connecting the two nuclei. The superwind is likely powered by both the nuclear star-formation and by the AGN. NGC6240 is thus an ideal target to study: a) the interplay between AGN and star-formation activity; b) the mechanism of transport of energy from the nuclei to the gas in the outer parts of the galaxy; c) how the molecular gas is heated by the winds.

We present in this work CO(1-0) maps obtained with the IRAM Plateau de Bure Interferometer (PdBI) in the D and A array configurations. These data have lower spatial resolution than previous works (Engel et al. (2010), Iono et al. (2007), Nakanishi et al. (2005)), but the useful bandwidth is much broader and the noise level is a factor > 2 lower. We also present a reanalysis of the Chandra X-ray, high spatial resolution data (available from the Chandra public archive). A ΛCDM cosmology (H$_0 = 70$ km s$^{-1}$ Mpc$^{-1}$; Ω$_m=0.3$; Ω$_\Lambda = 0.7$) is adopted.

3. X-ray observation and data analysis

NGC6240 was observed by Chandra on July 2001 for about 35 ksec. Reduced and calibrated data are available from the public CXO data archive. Results from these observations have been published by Komossa et al. (2003), and Lira et al. (2004).

4. Results

Figure 1 shows the continuum-subtracted spectrum of the CO(1-0) line, extracted from a polygonal region enclosing the source from the D array configuration data. The 3 mm continuum was estimated by averaging the visibilities in the spectral channels corresponding to the velocity ranges -3500 to -2000 km/s, and 2000 to 4000 km/s with respect to the systemic velocity. This range of velocities (not shown in Fig. 1 for clarity) is fully covered by the WideC Correlator and it is free from emission lines. Based on the data taken in the D array configuration, the continuum emission peaks at ~0.16, 0.82 arcsec off the phase tracking center, and has a flux density of 12.7 mJy. This is consistent with the 1 mm continuum reported by Tacconi et al. (1999), assuming a radio spectral index of 0.7. Two components of the radio and mm continua, centered at the position of each AGN, are found in maps with higher spatial resolution (Tacconi et al. 1999, Colbert et al. 1994). Our data from the D configuration do not allow to spatially resolve these two components. The continuum map shows one component whose fitted size is 1 ± 0.1kpc (FWHM), assuming a circular gaussian model. The 1 mm and radio (8 GHz) continua are consistent with non thermal synchrotron emission. The CO line peaks close to the assumed systemic velocity (~50 km/s). Broad and asymmetric wings extend to at least ~600 km/s on the blue side and ~800 km/s on the red side of the line peak. The full width at zero intensity (FWZI ~ 1400 km/s) is broader than that of CO(2-1) and CO(3-2) reported by Engel et al. (2010) and Iono et al. (2007).

In particular, the blue side of the line covers a larger velocity range than the previously reported ~450 km/s (Bryant & Scoville 1999, Tacconi et al. 1999, Engel et al. 2010, Iono et al. 2007, Nakanishi et al. 2005), probably due to the larger bandwidth and the better sensitivity of the new PdBI receivers.

Figure 2 shows the integrated maps from the D configuration data of the CO core emission (~50 to 50 km/s) and of the redshifted velocities (from 400 to 800 km/s with respect to the systemic velocity). The axes show the coordinate offsets with respect to the phase tracking center, (ra, dec)=(16:52:58.9, 02:24:02.9). The positions of the two AGN nuclei from VLBI observations (Hagiwara et al. 2011) are indicated by crosses. The
CO core emission is elongated in the north-south direction on scales of 10″, and shows a faint south-western elongation. The map of the red wing shows a strong compact source, of size ~1.7 kpc, co-spatial with the narrow core emission, and an elongation in the east-west direction with a position angle of 80 degrees. Fitting an elliptical gaussian model in the uv plane gives a flux of 11.4 Jy km/s for this high velocity, red-shifted component. The uv-fit results are reported in Table 1.

4.1. Blue-shifted CO emission

We now examine in detail the blue-shifted emission of CO. We find complex morphology, extended on scales from a few arcseconds to 15-20 ″. Figure 2 shows CO(1-0) maps at different velocities, from -400 to -100 km/s in channels 20 MHz (=53.3 km/s) wide, for the D and A configuration data. Each contour in Fig. 3 is 5σ (limited to 20σ for clarity). Two structures are particularly prominent: emission extended eastward out to at least 15″ with velocities from -400 to -200 km/s, and emission extending southwestward with velocities from -200 to -100 km/s. The most prominent emission is located eastward from the nuclei, i.e. approximately perpendicular to the line connecting the galactic nuclei, in the velocity range -400 to -150 km/s. From this, a structure showing velocities of ~ -260 km/s develops in the southern direction, likely a tidal tail remnant of the merger. This shows substructure, in the form of three main clumps of CO emission, and it coincides with the smooth structure seen by Bush et al. (2008) at 8 μm, and tracing dust through emission by poly-aromatichydrocarbons (PAHs). Figure 3 (lower panels) shows the maps obtained by merging the data from the D and A configuration. The synthesized beam is intermediate between those of the two and allows for better spatial resolution of the thin, jet-like structures, to better follow their alignment with the emission at other wavelengths. In the merged maps, we estimate, that for the central region (around the nuclei) we are missing ~ 33% of the flux.

Figure 4 shows two spectra extracted from circular regions of 2″ radius centered on the eastern and southwestern features. The spectra were extracted from the cleaned data cubes in regions that enclose the extended structures shown in Fig. 3. These spectra are presented for the purpose of showing the emission line peak velocity and line-width, and should not be used to derive the fluxes. Here we derive the line fluxes from the visibilities of D configuration data. We derive the line intensities of the two blue-shifted structures and of the nuclear region by fitting in the uv-plane the visibilities of the compact D configuration array data. The fit in the uv-plane yields the flux at zero-spacing. First, we fit the central region around the two nuclei (see Fig. 2, left panel), with the combination of two elliptical gaussian models, which yield a line intensity I_{CO} = 213 Jy km/s. The results of the fit are reported in Table 1. The fit produces a residual table where the visibilities of the central component have been subtracted. To derive the line intensity of the blue-shifted, extended structures, we fit the residual visibilities using two elliptical gaussians. The derived line intensity is 49.3 Jy km/s (over 600 km/s) for the eastern emission region, and 32.5 Jy km/s (over 400 km/s) for the south-western streamer. Summing these three components, we obtain a total integrated CO intensity of 295 ± 29 Jy km/s, in agreement with both Solomon et al. (1997) single dish observations (310 Jy km/s), and with the interferometric flux (324 Jy km/s) of Bryant & Scoville (1999).

Note that the emission of each blue-shifted region is 4 to 7 times fainter than the central part of the galaxy. As seen in Fig. 3, both these structures are spatially resolved. The eastern component is found 7.6″, 1.3″ off the phase tracking center. The south-western one is found at -6.4″, -6.8″ off the phase center. The fit with elliptical gaussians gives sizes of 14.4″ × 8.2″ for the eastern blob, and 8.3″ × 4.4″ for the south-western blob.

Figure 5 (left panel) shows the Wide Field Planetary Camera (WFPC2 F673N) image from the Hubble Space Telescope (HST), which includes the galaxy’s Hα emission (Gerssen et al. 2004), with overlayed contours of the blue-shifted CO(1-0) emission at -400 km/s and -100 km/s. The WFPC2 image shows that the Hα nebula comprises five main bright filaments: two southwards of the nuclear region, one located in the western region, and two eastwards from the nuclei. We note that the CO emission with velocity -100 km/s is located on the southwestern dust lane, in between two Hα filaments. An elongation of this component toward the northern dust lane is also visible. The CO emission centered at -400 km/s first follows the eastern elongation of the Hα emission, and continues further eastward and southward. We also show the X-ray emission at 1.6-2 keV, centered on the highly ionized Si emission (white contours). Note...
Fig. 3. Upper panel: CO(1-0) maps from the compact array data, in velocity bins of 20 MHz each (velocity labels are rounded off), showing the detection of blue-shifted CO, including structures extended on scales of 10-15″. The positions of the two AGN nuclei are shown by crosses. The synthesized beam is shown on the first panel only, for clarity. Each contour is 5σ (limited to 20σ). Lower panel: maps from merged data of the D and A configurations in the same velocity channels. The synthesized beams are shown in the bottom-left corners.

that the X-ray data trace remarkably well the Hα emission. In particular, the soft X-ray emission is coincident with the eastern Hα, H2 (see fig. 9 in Max et al. 2005) and CO elongation. This leads us to investigate further the association of the X-ray emission with the Hα, H2 and CO emitting gas.

4.2. X-ray spatially resolved spectroscopy

We extracted a spectrum from the X-ray Chandra data at the position of each of the five Hα filaments described above, and combined them. The extraction regions are shown in Figure 6. A background spectrum has been extracted from a source free
region at distances of 2 to 5 arcmin from the nuclei of the galaxy of 25 arcmin² size, in order to avoid the contamination from the diffuse X-ray emission, which is still seen on scales of 1 arcmin away from the nuclei. The background-subtracted X-ray spectrum is plotted in Fig. 7. Strong emission lines are visible at about 1.3-1.4 keV, 1.7-1.9 keV and 2.3-2.4 keV. At these energies the ionized emission from Mg, Si and S is expected. We fitted the spectrum using XSPEC and adopting χ² statistics. The spectrum was binned to have at least 30 counts per channel. We limited the fit to the 0.5-7 keV band (440 original channels, 67 bins), where the instrument response is best calibrated and to avoid strong background lines at high energy (see e.g. the Chandra background spectrum in Fiore et al. 2011). We started modeling the spectrum with a thermal equilibrium gas component (MEKAL in XSPEC), reduced at low energy by photoelectric absorption by gas along the line of sight. This model is clearly inadequate to reproduce the observed spectrum, giving a χ²=179.5 for 63 degrees of freedom (DOF) and large residuals at 0.8-0.9 keV, 1.2 keV, 1.8 keV and above 4 keV. We then added a second thermal equilibrium gas component to the model. Figure 7 shows the best fit model with 8 free parameters (two temperatures, two metal abundances, two normalizations and two absorbing column densities). The best fit χ² is 93.3 (59 DOF). Note the rather strong positive residuals at 1, 1.4, 1.8, 2.2 keV, i.e. the position of the Mg, Si, and S line complexes. Stronger line emission is expected in non-equilibrium models, because of the broader ion distribution with respect to thermal equilibrium models at the same temperature and metal abundances. In particular, shock models, like XSPEC PSHOCK are known to produce spectra with prominent line emission. We therefore fitted the spectrum with a model including a thermal equilibrium component and a shock component. The best fit χ² is now 62.1 (58 DOF). The improvement in χ² with respect to the two component thermal-equilibrium model is significant at the 99.9997% confidence level (using the F test). Residuals with respect to the best fit model do not show any systematic deviation. Figure 8 shows the best fit unfolded (i.e. corrected for the response matrix of the instrument) spectrum with the identified contributions of the thermal equilibrium and shock components. We conclude that the X-ray analysis supports the idea that shocked gas is present at the position of strong Hα emission, both in the nuclear starburst and in the elongated filaments.

Fig. 6. The Chandra X-ray map of NGC 6240 in the energy range 0.3-4 keV. The circles indicate the regions were we extracted the X-ray spectra. The region for the background extraction is outside the limits of this map, at 2-5 arcmin from the nuclei.

5. Discussion and conclusions

We have obtained deep 3 mm maps of the archetypical interacting galaxy NGC6240 with the IRAM PdBI, covering a velocity range of 10.000 km/s. The CO(1-0) line shows strong blue and red wings extending from −600 km/s to +800 km/s with respect to the systemic velocity. The line (FWZI= 1400 km/s) is significantly broader than that previously reported by Tacconi et al. (1999), Engel et al. (2010), and Iono et al. (2007). The systemic CO emission shows a north-south elongation over at least 10″. Elongation in the same direction is seen in the CO(1-0) maps of Bryant & Scoville (1999), and in the CO(2-
maps of Tacconi et al. (1999), and Engel et al. (2010) on 10 times smaller scales. The CO luminosity of this region is 
\[ L'(\text{CO}) = 5.7 \times 10^{9} \, \text{K km s}^{-1} \, \text{pc}^{2} \]. We derive an estimate of the molecular gas mass in this region, assuming the standard CO to \( \text{H}_{2} \) conversion factor, \( \alpha = 0.8 \, M_{\odot} \, (\text{K km s}^{-1} \, \text{pc}^{2})^{-1} \) (units omitted hereafter). We find \( M(\text{H}_{2}) = 4.5 \times 10^{8} \, M_{\odot} \), consistent with the value derived from CO(2-1) for this region by Tacconi et al. (1999).

We were able to identify new components. We find CO emission extended up to distances of 15-20\arcsec from the galaxy centers (7-10 kpc at the distance of NGC6240). In particular, we find strong emission blue-shifted by ~ 150 to 400 km/s extending eastward by at least 15\arcsec from the nuclei, and by 100-200 km/s extending south-westward on a similar scale. The presence of the latter component was suggested by the interferometric CO maps of Bryant & Scoville (1999), although with low significance.

The CO southwestern emission coincides with the dust lane seen in HST images (Gerssen 2004, also see Fig. 5) and in the IRAC 8 \( \mu \)m image (Bush et al. 2008). This large scale dust distribution has been interpreted as due to a tidal tail curving in front of the system (Gerssen et al. 2004, Yun & Hibbard 2001). Molecular gas is associated with this tidal tail, a situation reminiscent of M82, where Walter et al. (2002) found molecular gas in the tidal tales correlated with dust absorption features. The integrated CO luminosity of the southwestern emitting region is 
\[ L'(\text{CO}) = 8.7 \times 10^{8} \, \text{K km s}^{-1} \, \text{pc}^{2} \]. For the conversion from CO luminosity into molecular gas mass \( M(\text{H}_{2}) \), we conservatively adopted the lowest conversion factor found in the giant outflows and streamers of M82 (Weiss et al. 2001), \( \alpha = 0.5 \). The mass of the molecular gas in this region is thus \( M(\text{H}_{2}) = 4.3 \times 10^{8} \, M_{\odot} \), 4-to-10 times the \( \text{H}_{2} \) mass in the streamers of M82 (Walter et al. 2002, derived for the same conversion factor). This estimate likely represents a lower limit to the molecular gas mass in this streamer. The physical size of the southwestern tidal tail is however at least 15\arcsec, i.e. 7 kpc, 4-7 times larger than the streamers in M82 (Walter et al. 2002). The CO extended emission to the north (see Fig. 2, left panel) coincides with a dust lane seen in HST images (Gerssen et al. 2004), and might be associated with another streamer. The detection of molecular streamer(s) in NGC6240 confirms that the molecular gas is severely affected by galaxy interaction, and that the redistribution of molecular gas is likely the trigger for the strong starburst activity in the central region of NGC6240.

The blueshifted eastern CO emitting region is not associated with the dust lanes mentioned above, but follows a Hz filament, and PAH emission observed at 8 \( \mu \)m (Bush et al. 2008). The emission-line nebula seen in Hz images (Gerssen et al. 2004) is interpreted as evidence of a superwind that is shock heating ambient ISM. The Hz emitting filaments are aligned east-westward, perpendicular to the dust lanes and to the line connecting the two nuclei. The X-ray emission is associated with the Hz filaments (Lira et al. 2002). In particular, strong soft X-ray emission is coincident with the north-eastern filament (N-E region in Fig. 6). We re-analyzed the Chandra X-ray data and found strong evidence for shocked gas at the position of the Hz filaments. The presence of shocked gas in the NGC6240 system...
of the eastern blue-shifted CO emission coincides with the position where Bland-Hawthorne et al. (1991) and Gerssen et al. (2004) found a large velocity gradient of the ionized gas (the velocity decreasing, roughly, north to south). No significant radio continuum emission is detected in this region in the VLA maps of Colbert et al. (1994). The blue-shifted molecular gas in this region might be a tidal tail, left behind during the merger. However, its association with strongly shocked gas suggests that a shock is propagating eastward and is compressing also the molecular gas, while crossing it.

The integrated luminosity of CO in this region is \( L'(\text{CO}) = 1.3 \times 10^{14} \text{ K km s}^{-1} \text{ pc}^{2} \), corresponding to a gas mass \( M(H_2) = 7 \times 10^6 \text{ M}_\odot \) (assuming again \( \alpha = 0.5 \)). Hypothesizing that this outflow originates from the southern, luminous AGN (or from both the AGN), we derive here a mass loss rate. We assume that the molecular outflow is distributed in a spherical volume of radius \( R_{\text{off}} = 7 \) kpc (i.e. the distance of the eastern blob from the AGN), centered on the AGN. If the gas is uniformly distributed in this volume, the volume-averaged density of molecular gas is given by \( < \rho_{\text{off}} > = 3 M_{\text{off}} / \Omega R_{\text{off}}^2 \), where \( \Omega \) is the solid angle subtended by the outflow and \( M_{\text{off}} \) is the mass of gas in the outflow (Feruglio et al. 2010, Maiolino et al. 2012). This assumption is an approximation, and evidently cannot represent the complexity of the system, but can provide a rough estimate of the mass loss rate. Based on this geometry, we can derive a mass loss rate by using the relation:

\[
M(H_2) \sim \eta \Omega R_{\text{off}}^2 \rho_{\text{off}} < 3 \eta \frac{M_{\text{off}}}{\Omega_R^2},
\]

where \( \eta \) is the terminal velocity of the outflow (\( \sim 400 \) km/s). This relation yields a mass loss rate of \( M \sim 120 \text{ M}_\odot /\text{yr} \). The H\(\alpha\), H\(2\) and CO(1-0) maps suggest that the outflow is most likely conical. In this geometry, since the mass loss rate is independent of \( \Omega \), the mass outflow rate would be equal to the spherical case if there are no significant losses through the lateral sides of the cone. As it is observed in other local massive outflows (Cicone et al. 2012, Aalto et al. 2012), the outflowing gas is likely characterized by a large range of densities, ranging from low density gas to dense clumps, which would increase the mass flow rate. In addition, the mass flow rate would obviously be larger than our previous estimates if \( \alpha \) is significantly higher than 0.5. To date, this is the lowest conversion factor measured in an extragalactic object. This said, it is unlikely that the mass loss rate is smaller than several tens \( \text{M}_\odot /\text{yr} \), and it is likely as big as a few hundreds \( \text{M}_\odot /\text{yr} \). The kinetic power of the outflowing gas is given by the relation \( \dot{P}_k = 0.5 \eta v^2 M = 6 \times 10^{32} \text{ erg s}^{-1} \). The age of the outflow is \( > 2 \times 10^7 \) years, since it is observed at about 7 kpc distance from the southern nucleus. The star-formation rate at the position of the eastern filament can be evaluated through both the H\(\alpha\) luminosity and the X-ray luminosity (e.g. Kennicutt 1998, Ranalli et al. 2003). The 0.5-2 keV X-ray luminosity at the position of the East filament is \( 0.5 \times 10^{41} \text{ erg s}^{-1} \), which according to Ranalli et al. (2003) would imply a star-formation rate of 10-20 \( \text{M}_\odot /\text{yr} \). This estimate is derived by assuming that all the X-ray luminosity is due to star-formation. In section 4.2 we showed that at least a fraction of the X-luminosity is due to a shock, therefore the SFR derived from the X-ray is an upper limit. This would suggest that the outflow is not pushed by SN winds. Indeed, the power transferred to the ISM by a star-formation driven wind is given by \( P_{\text{SF}} = \eta \times 7 \times 10^{41} \times \text{SFR} = 10^{42} \text{ erg s}^{-1} \), where \( \eta = 0.1 \) is the standard mass-energy conversion (see e.g. Lapi et al. 2005). We conclude that it is unlikely that the molecular flow is powered by star-formation. Instead, star-formation in this region is likely in the process of being quenched by the outflow.
However, we cannot exclude that star-formation in this area is induced by the compression caused by the propagating shock. We detected a red-shifted component with velocity 400 to 800 km/s with respect to the systemic velocity (Fig. 2), centered around the two AGN nuclei. Interestingly this emitting region is elongated in the same east-west direction as the blue-shifted emission discussed above, although on smaller scales (~1.7 kpc in diameter). We derive a CO luminosity of this component of L'(CO)=3.0x10^6 K km s^{-1} pc^2, which converts into a gas mass of M(H2)=1.5x10^6 M⊙ under the same assumptions given above for the CO-to-H2 conversion factor. The large velocity of this component suggests that the AGN might contribute to the dynamics of this gas (Sturm et al. 2011).

Given the complex dynamics and morphology of this system, it is not trivial to disentangle and quantify the relative role of each mechanism. Probably several mechanisms are acting contiguously: mainly the radiation pressure of the AGN together with dynamic shocks induced by the merger event. High resolution X-ray observations will help to clarify the interaction between the star-forming regions and the CO extended structures (Wang et al. in preparation, conference communication). The high spatial resolution data taken in the A array configuration indeed provide new insights on the nuclear region, which will be addressed in a separate publication (Feruglio et al. 2012, in preparation).

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