Signatures of Jet Impact on the ISM in Radio Galaxy 4C+29.30

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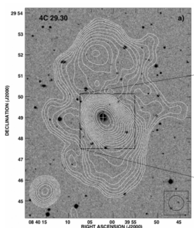
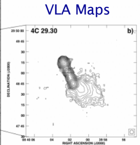
ABSTRACT: We present results of a deep Chandra observation of a low-z radio galaxy with signs of the complex interactions between the radio plasma and ISM. The Chandra image shows regions of enhanced X-ray emission correlated with radio structures along the jet axis. The larger scale X-ray diffuse emission outside the radio source correlates with the morphology of known optical line-emitting regions. We measure the temperature of the ISM and identify regions heated by weak shocks with the Mach number of 1.6. The X-ray emitting gas is most likely heated by the radio source expanding within this galaxy. The multi-band data supply a complex view of the source, signaling feedback processes closely associated with the central active nucleus.

Radio Galaxy

VLA Maps



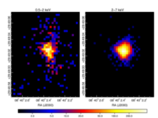
1.4GHz VLA D-array contour overlayed on DSS optical image. The size of the radio source is ~8 arcmin.



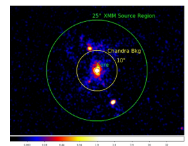
1.4GHz VLA B-array map of the central ~50 arcsec radio structure

Low redshift galaxy z=0.067

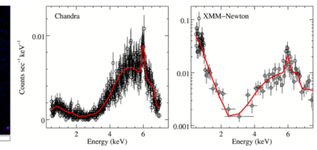
Hidden AGN Nucleus



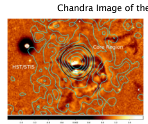
Chandra Image of the Nuclear Region



Chandra and XMM spectral extraction regions - core and backgrounds as marked in the image



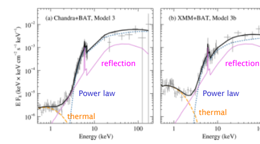
X-ray Spectra overlayed with the best fit model. Note the soft excess in XMM is due to the central galaxy emission. Chandra shows that the AGN soft emission is absorbed - see dust lane in the HST image.



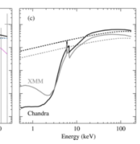
HST unsharp mask image with Chandra contours. Dust lane visible across the nucleus -> absorption of the central AGN

Complex X-ray emission of the central region:
- Hard power law (Γ=1.56 (+/-0.15) absorbed by N_H~5x10^{23} cm^{-2}
- Reflected emission with Fe-Kα line at 6.4keV
- Thermal emission - kT = 0.6 (+/-0.07)
- Marginal contribution of a scattered power law to the soft X-ray band, <0.25%

Source belongs to a class of hard X-ray selected hidden/buried AGN. It is a radio loud source and only 9% of the sources in this class are radio loud.

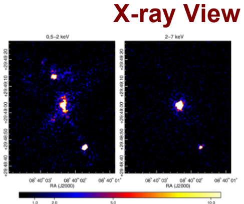


Unfolded spectra and best fit m odels fit to the Chandra-Swift BAT and XMM-Swift BAT Spectra

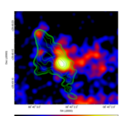


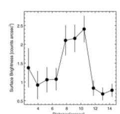
Indication for the intrinsic power law variability between XMM and Chandra observations

X-ray View of the Galaxy



Chandra ACIS -S images smoothed on the same scale. Nuclear emission and the hot spot are strongest emitters in the hard band.





Northern Lobe: Chandra Image and Radio Contours. Right show the X-ray surface brightness across the arm - corralated With the velocity jump in the optical-line-emitting gas.

X-ray Properties

The soft 0.5-2 keV X-ray emission spreads over the entire radio source with several emission regions: Central diffuse emission, Southern jet, Hot Spot and some diffuse emission related to the Southern Lobe. To the North the strong diffuse X-rays correspond to the Northern Radio Lobe and Hot Spot.

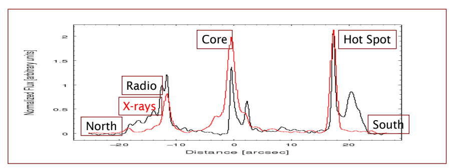
Nucleus is highly absorbed and dominates the hard (2-7 keV) emission. We measure N_H = 4.96 (+/-0.14) x 10^{23} cm^{-2} and a power law slope of Γ=1.56 (+0.17/-0.04) with the hard unabsorbed X-ray luminosity equal to L_x(2-10keV) = 5.0±0.5 x10^{43} erg/s

The X-ray emission of the Northern Hot spot is very soft and well fit by a thermal model with kT=0.54±0.5 keV. The HS is also absorbed with NH ~10^{21} cm^{-2} and the unabsorbed luminosity is equal to L_x(0.5-2keV) = 1.7x10^{41} erg/s. The HS emission disappears in the hard band. The origin of this hot spot is most likely related to the jet interaction and heating of large amount of gas there.

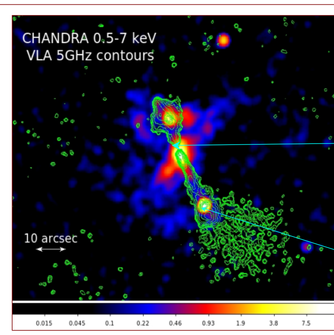
The X-ray emission of the Southern Hot Spot is extremely bright in X-rays. It is also hard in contrast to the Northern HS. The total luminosity of this HS is equal to Lx(0.5-10keV) = 1.3x10^{41} erg/s.

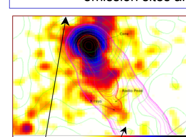
X-ray Jet emission is detected to the South, although the emission is not continuous, but in form of enhancements along the radio jet. The continues emission is only visible in the central region but it is hard to disentangle it from the diffuse thermal emission of the hot gas there.

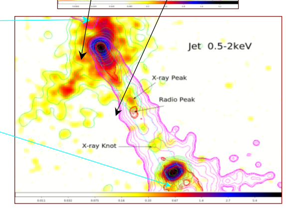
Radio and X-ray Alignments



- Radio features occur in pairs;
- X-ray peaks show as single features;
- The Southern Hot Spot is the brightest feature in radio and X-rays.
- Radio and X-rays peaks are offsets in secondary features, while the strongest emission sites are aligned.







Summary and Conclusions

- Chandra image reveals a complex X-ray morphology on ~50 kpc scale indicating intricate interactions between radio outflow and the ISM.
- There is a strong morphological correspondence between the main radio source components and the detected X-ray emission features suggesting that the radio source heats up the gas and dissipate the initial jet energy.
- X-ray emission of the hot spots is particularly complex with different and distinct emission components (both thermal and non-thermal/synchrotron).
- A significant fractio of the jet energy goes into heating surrounding gas. Support for heating the ambient medium via weak shocks - Mach number equal to 1.6. Only a small amount of the jet power is needed to accelerate cooler (optically emitting) clouds
- An absorbed AGN nucleus is powering the jet. It is relatively powerful with the unabsorbed luminosity >5x10^{43} erg/s, but the accretion state of the central BH is still not clear, as the optical emission is buried within the dust. We estimated the black hole mass to be close to 10^8 M_{sun} with L_{bol}/L_{Edd} >0.1

References

Siemiginowska, A., Stawarz, L., Cheung, C.~C., et al. 2012, ApJ , 750, 124

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Acknowledgments

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