Offsets between X-ray and Radio Emission: A step towards understanding the structure of extragalactic jets

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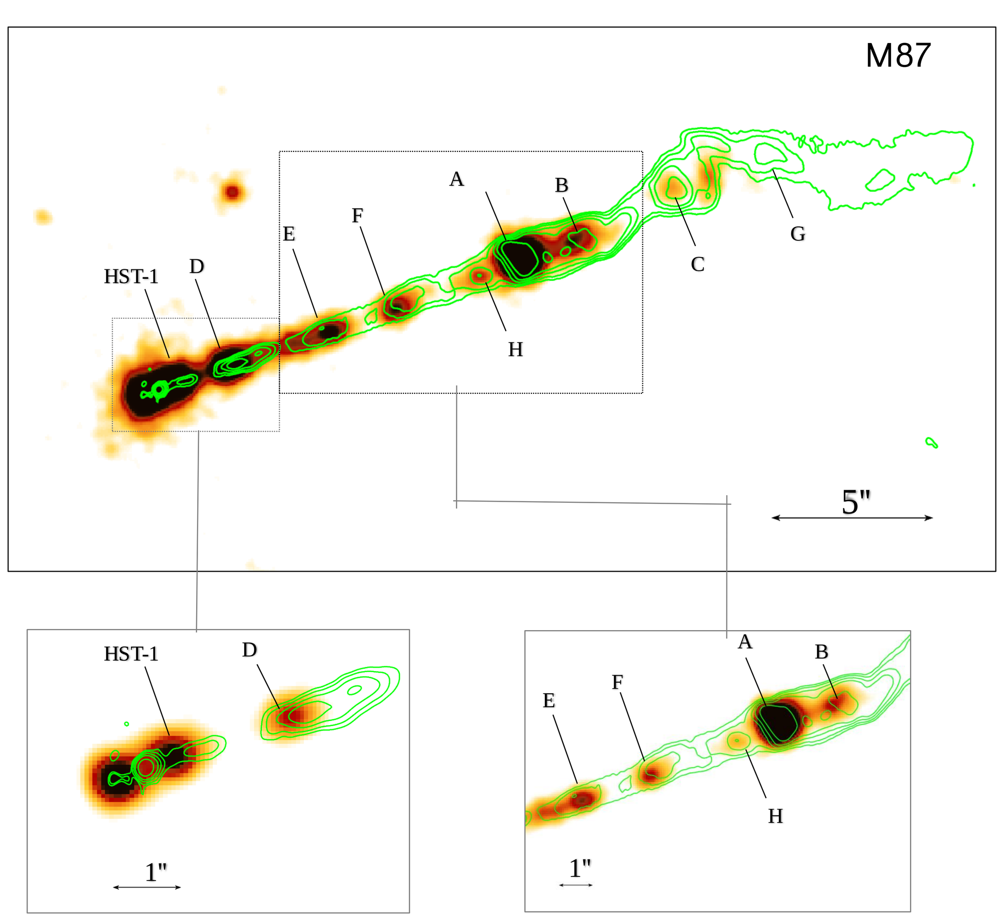
Abstract

Reported in the literature are a few extragalactic jets which show significant offsets between X-ray and radio emission in knots and hotspots. These offsets have occurred in jets with a wide range of jet powers. Despite this fact, various single-zone emission models were employed to explain the X-ray emission from the jets. We have undertaken a detailed study on all the Chandra detections and are finding that offsets are more the norm than an exception. This questions the applicability and conclusions of single-zone models.

Introduction

Traditionally, numerical and analytical single-zone emission models, where the emission is assumed to come from a single population of electrons, were employed to explain multi-wavelength emission from the jets in radio loud AGN. This directly implies the coincidence of the radio and X-ray emitting features along the jet. But, offsets between X-ray and radio emission were reported initially in a few close by jets like M87 and 3C31 and the count grew over time.

We've undertaken a detailed study of all the X-ray jets that were detected by Chandra to date to study the offsets with their radio counterparts. High resolution radio maps are made, and wavelet-decomposition is used to detect sources in the co-added, exposure corrected subpixel Chandra images in addition to a careful visual inspection. We are finding that offsets are common in these jets. This contradicts the predictions of single-zone models. We suggest that a careful consideration must be given to these offsets while modelling the multi-wavelength emission, especially in highly aligned sources where low resolution and projection effects can easily nullify any possibly existing offsets.



VLA 8.4GHz (0.2"; core subtracted) + X-ray bin size: 0.125(0.0615"). This is one of the early jets that was reported to have offsets between X-rays and radio.

Here, high resolution images reveal a radio knot between the core and HST-1. Knots B,D,F show small X-ray first offsets while the X-rays are coincident with the radio in knots A and H.

Offsets!

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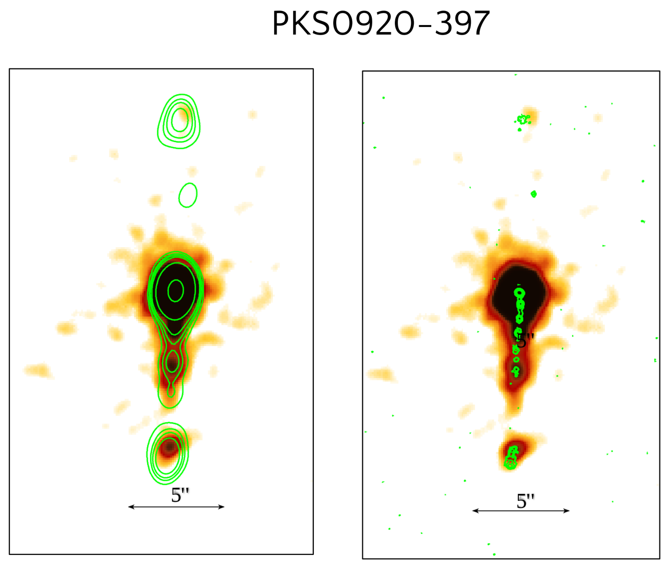
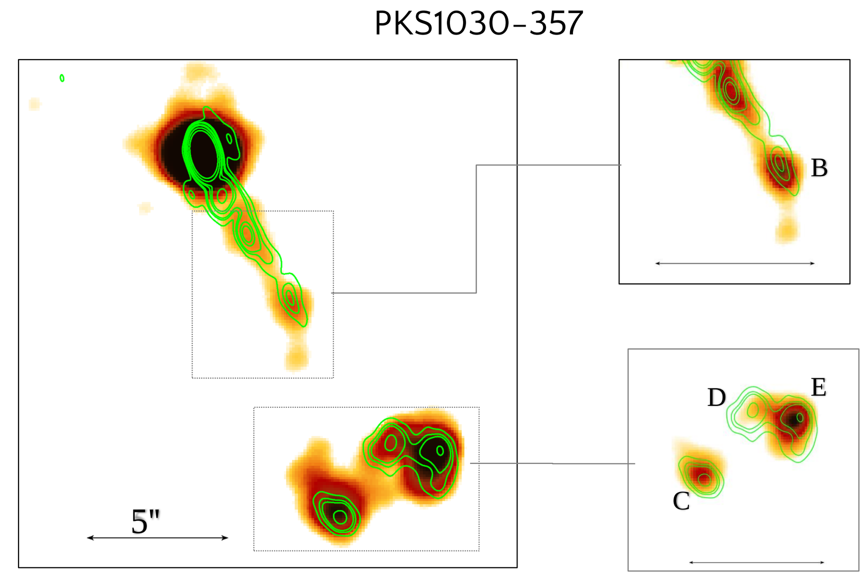


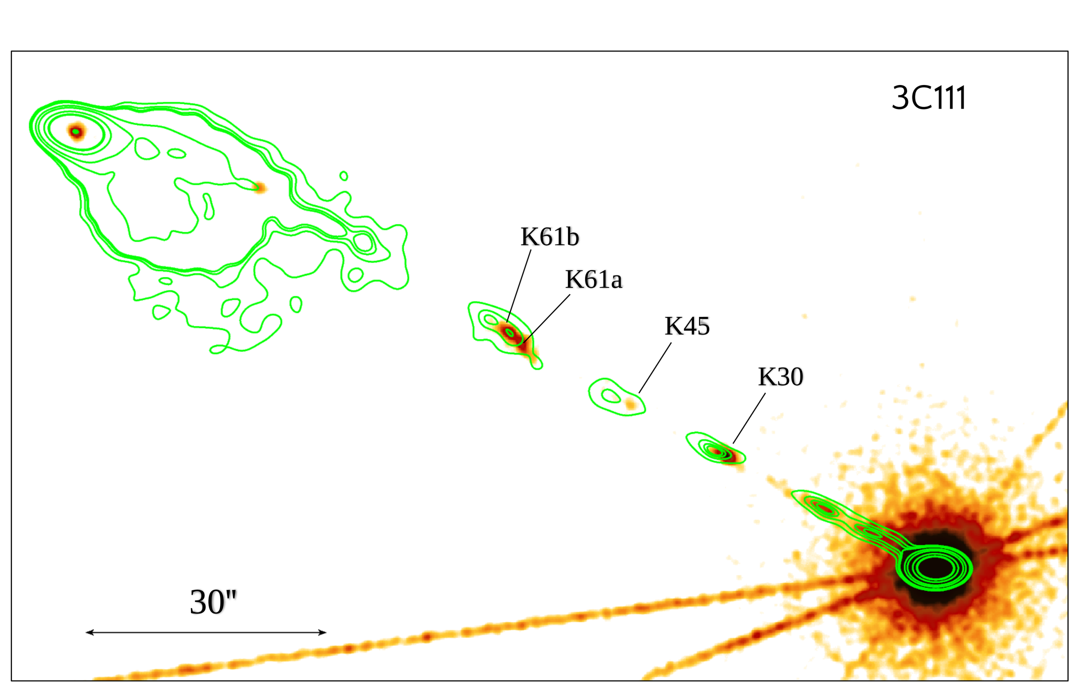
ATCA 8GHz (1.53") ALMA Band 3 (0.15")

X-ray hotspots, where the jet presumably enters the hotspot region, are often coincident with faint radio knots both which appear upstream of a bright radio hotspot. This would appear as an offset if the fainter radio knot is not resolved in the radio image.

PKS1030-357

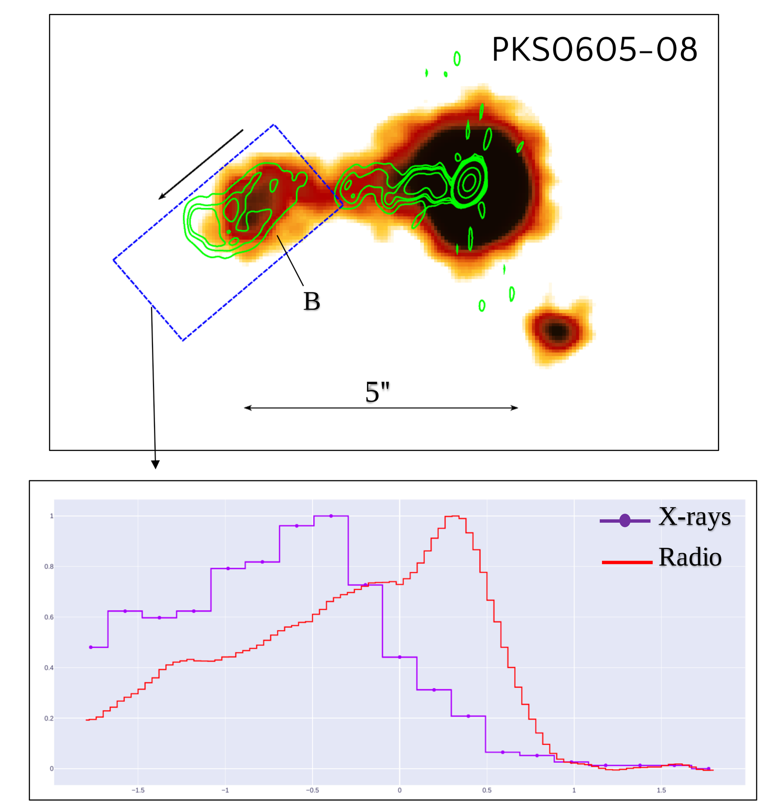


ATCA 20GHz (0.5") contours + X-ray bin size: 0.2 (0.984"). The X-rays peak slightly upstream of radio knot B. While the X-rays clearly peak before hotspots C and E, their pointed morphology in the upstream direction of the jet suggests the presence of fainter radio knots overlapping the X-ray peaks.

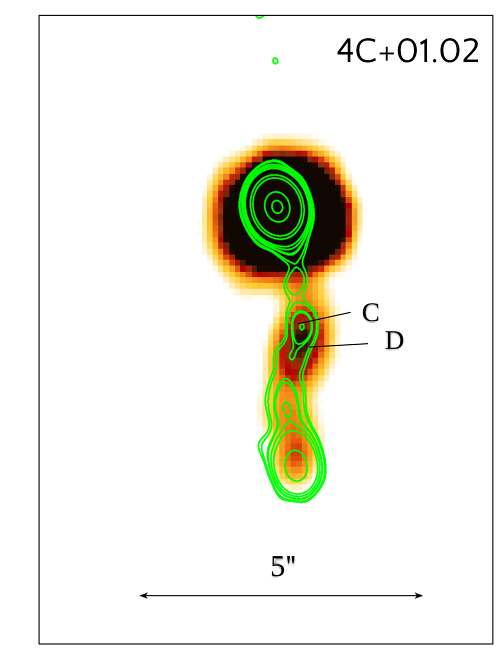


VLA 1.4GHz (4.3") contours + X-ray bin size: 0.2 (0.0984"). The X-rays peak closer to the core than the radio in the knots K30, K45, K61a, K61b and also in the northern hotspot.

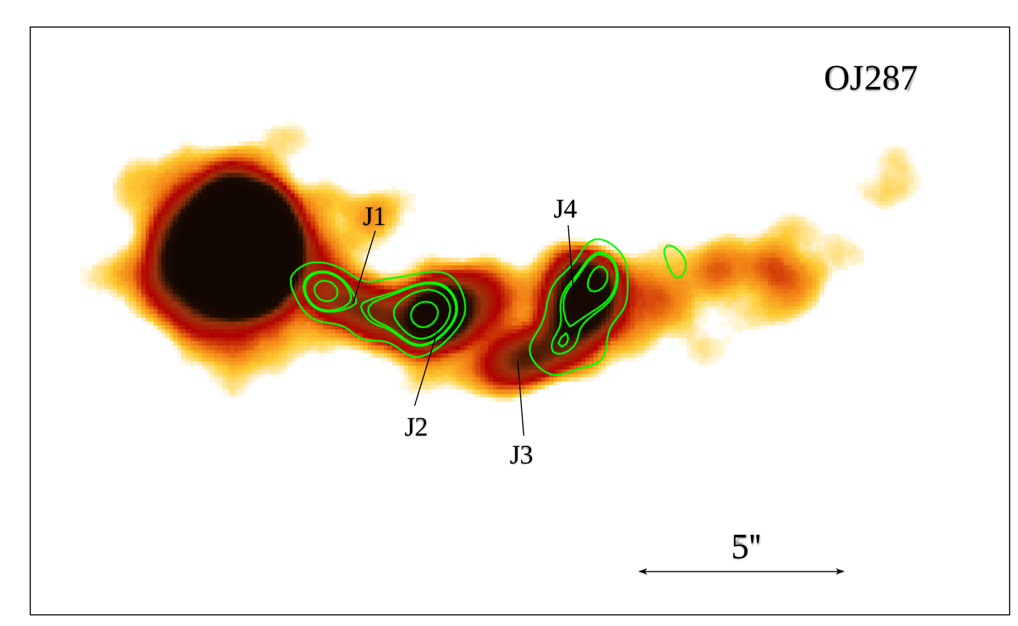
More Offsets!



VLA 8.4GHz (0.2") contours + 0.2 X-ray bin size. The X-rays fade away before the radio in knot B. And, the distance between the X-ray and radio peaks is at least 0.5"(3.3 kpc projected) which is much greater than the astrometric error of ~0.1".

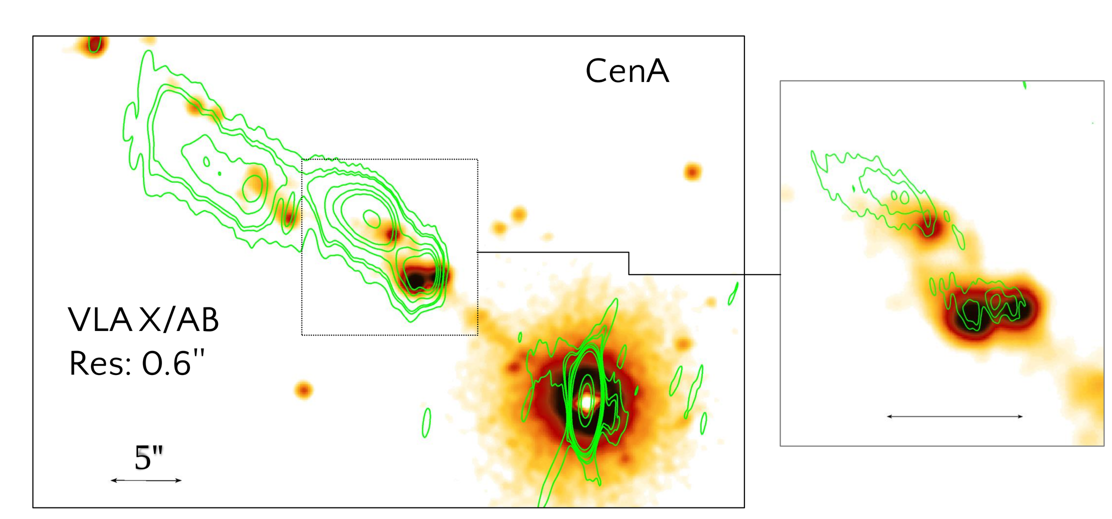


VLA 4.6GHz (0.33") contours + X-ray bin size: 0.2. The X-ray enhancement at knot C was previously interpreted as an increase in the doppler factor assuming that it was co-spatial with the radio. But, analysis with wavdetect reveals two X-ray source detections both downstream of knots C and D.



VLA 1.4GHz (1.3") contours + X-ray bin size: 0.2 (0.984"). X-ray knot J3 and J4 display X-ray first offsets while J2 displays a radio first offset. Also, there is a faint radio knot possibly overlapping J1. Previously, J4 was reported as a radio first offset while offsets in J3, J4 weren't reported.

Previously proposed solutions for offsets



- **Synchrotron times lags + downstream advection[1]**
  - Initially used to explain offsets in M87, 3C273, 3C66B
  - But faint unresolved radio knots can be coincident with X-ray knots[2]. See Centaurus A for example.
  - X-ray variability in moving knots of Cen A are inconsistent with synchrotron cooling[3]
- **Faster moving knots in a slower outer flow + double shock structure (e.g., [4])**
  - Can explain the offsets in FR-II jets but fine is tuning required to explain generation of different particle populations at either ends of the shock
  - Doesn't have any preference for synchrotron or IC/CMB
- **Slow heavier moving knots in a fast-outer flow + single reverse shock[5]**
  - Cannot explain differences in transverse profiles: wide and flat-topping in radio knots vs. narrow and gaussian in X-ray knots.
- **Upstream magnetic turbulence caused by moving knots**
  - Can explain 'radio-first' offsets but cannot explain the apparent bends in the jet at knot locations (See OJ287)

Preliminary results

- >30% of the sources show offsets between radio and X-rays
- Offsets between radio and X-ray emission appear to be common in many X-ray jets. This warrants the use of multi-zone models to explain the X-ray emission.
- X-ray first offsets, where X-rays peak closer to the core than radio are much more common than their counterparts, the radio-first offsets.
- Phenomenologically, no difference between knots and hotspots has emerged yet.

References

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