Studying Complex Motion in Active Galactic Nuclei

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Abstract

AGN jets are observed shooting outward in opposite direction at speeds close to the speed of light and forming two huge radio lobes at the end sides of the jets. However, we are not sure if those jet components are moving with constant velocity, accelerating or having even more complex motions. Therefore, I focused on researching on the motions of the jets by analyzing the 121 components. Essentially, I used Monte Carlo simulation to generate 1000 simulated data and plotted their average deviation as histograms for better understanding their motions.

Introduction

Active galaxies differ from normal galaxies by emitting enormous amount of energy from their bright central region. These Active Galactic Nuclei (AGNs) are powered by a supermassive black hole and accretion disk of matter falling inward. Some AGNs have collimated jets of plasma shooting outward in opposite direction from the center of the host galaxy at nearly the speed of light. The jets are composed mostly of charged particles and the twisted magnetic field lines and emit synchrotron radiation (Bennett, et al 2014.)

One of the interesting things about the jets is the often observed superluminal motion. Some of the jets are observed moving at a speed faster than the speed of light which we know can never be true. We can understand this strange phenomenon by considering the directions the jets are flowing. When the jets are in a position where people on Earth can only observe one jet and the other is invisible, one of them is shooting almost parallel to our line of sights and the other one is beaming away (Homan, 2012.) Under this circumstance, the Doppler effect causes the observed speed to appear faster than the speed of light whereas the intrinsic speed is actually only slightly less than that. We still do not fully understand how these jets are collimated and accelerated to reach speeds so close to the speed of light.

This summer, I studied data from the 121 AGN jet features observed by MOJAVE program (Monitoring of Jets from Active Galactic Nuclei) for up to 20 years with the Very Long Baseline Array (VLBA). My goal was to identify complex motion in the jet flows that cannot be explained by simple acceleration.

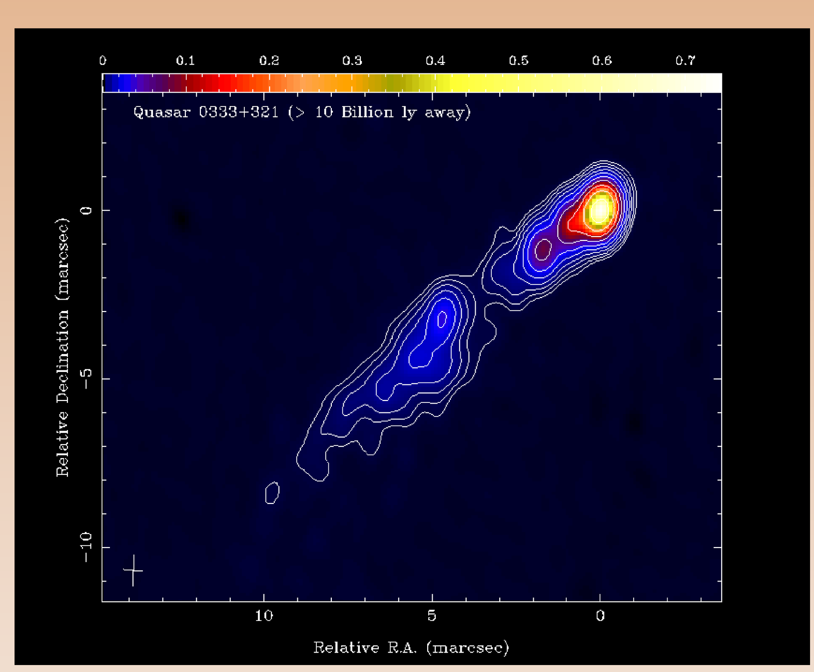

Figure 1: This is the image of jet 0333+321, epoch was 2016 June 16th. It is showing the jet is flowing to the left from the center of its galaxy, we study the jet motion by tracking those bright features.

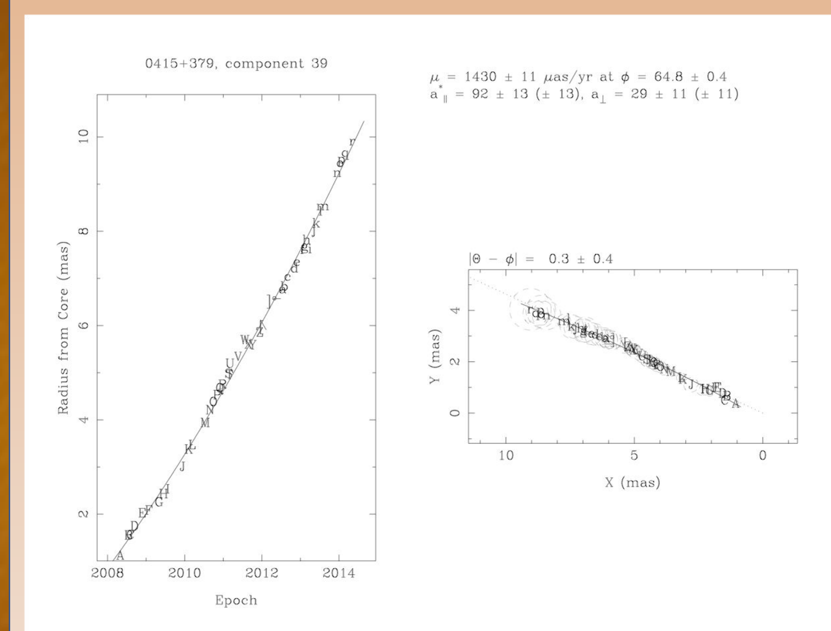

Figure 2:

This is a jet feature in the Active Galaxy 0415+379 This feature is gradually accelerating, it also shows more complex change in speed and direction.

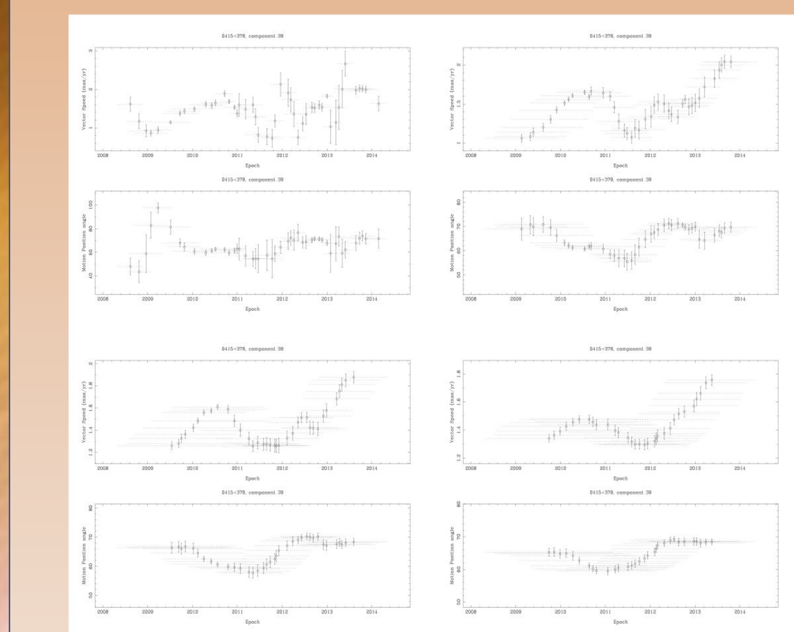

Figure 3:
Panels show speed and direction of jet 0415+379 component 39 fitted to short time "windows" consisting of 5 epochs (upper left), 10 epochs (upper right), 15 epochs (lower left) and 20 epochs (lower right)

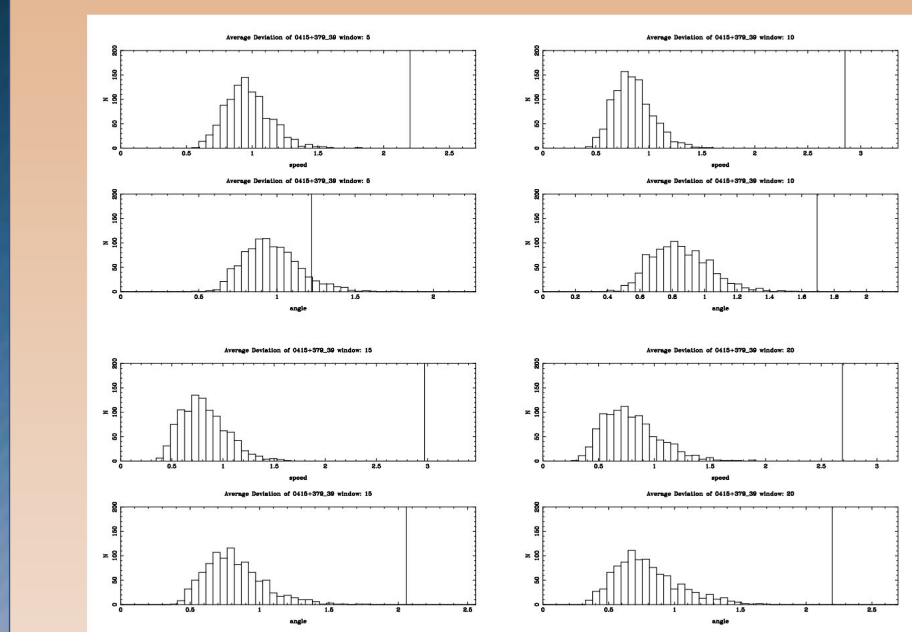

Figure 4
This is the merged histograms of jet 0415+379, component 39. The solid line in each of the panels represents the average deviation in the actual data from the acceleration fit. Those histograms of deviations from the acceleration motion found in the random Monte Carlo simulation matches those in figure 3.

Methods

As can be seen in Figure 2, 0415+379 component 39 seems to have a well acceleration fit and more complex change as described in the caption. We can investigate these changes in motion by fitting short time "windows" consisting of 5, 10, 15 or 20 consecutive epochs.

Figure 3 shows speed and direction of 0415+379 component 39 analyzed for these different window sizes. However, it's not clear whether the changes over time depicted in Figure 3 are due to real change in motion or random uncertainty in the measured component position. We want to detect complex changes in motion of jet features that go beyond our standard simple acceleration model. By running Monte Carlo simulation, random uncertainty could be added to every data points that's on the feature's acceleration fit and thus produce a new fitted motion. If the new curve looks like the original curve, it might indicate any changes in the original motion were contributed by noise and if not, they may be due to real changes in motion.

It provided a much more effective way of analyzing visually if the changes of speed in the original graph were caused by uncertainty or not. Secondly, it's more convenient for comparing the feature's speed and angle changes at the same time.

I created another program that calculates the average deviation between the source and the model fit and between the simulated data and the model fit for 1000 and more simulations. After those statistics were finally ready, I was able to create the final integrated program for analyzing all interested features based on the epochs input. As shown in Figure 4, the program generates a histogram of average deviation of 1000 simulation of the feature's speed and angle in terms of different window size and merges them together. The solid line in the histogram is the average deviation of the real data from the model fit, thus, the further away the line is, the more likely the complex motion changes we observe in the feature are real.

I applied these methods to all the 121 components with 30 or more epochs and ran the final program on these features and did a detailed analysis of their original data graphs and corresponding histograms.

Acknowledgement

I have used data from the MOJAVE program database (Homan,2012.)
I would like to express my special thanks of gratitude to my research advisor Dr. Homan who gave me this opportunity to do this research project and for his thoughtful guidance throughout my research. I would also like to thank Laurie Bukovac & David Hodgson Endowed Fund for funding my research.

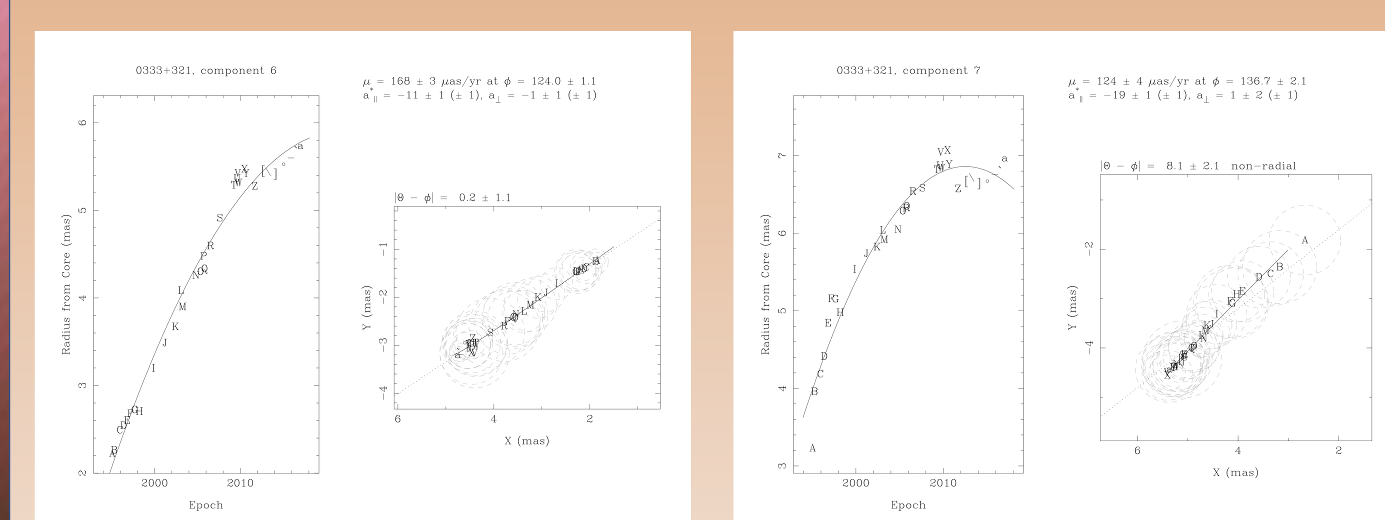

Figure 5: motion plots of AGN 0333+321 component 6, 7
These two special cases show extreme similarities in their motion pattern.
[see specifics in Results and Discussion]

Results and discussion:

In the database of MOJAVE, there are 121 jet features that have 30 or more epochs, I ran the analysis described in the method section above on each of them. As a result, I grouped those features by their overall motions.
I put them into 3 broad categories based on their motion behaviors. They were a) the 48-"jittering" motion that roughly stayed stationary b) the 54-outward motion along the jet and c) the 19-transverse motion roughly perpendicular to the jet.

Although the stationary motion/ jittering motion and the transverse motion are both interesting cases, we focus on more detailed data we have of the outward motion because it might be a good indication of the intrinsic flowing motion of the jet. [see results in Figure 5]

Out of the 54 outward motion, there were 31 cases with complex motion and 20 cases were likely to be having their motion contributed by noise also with 3 borderline cases.

Furthermore, I focused my results only on the real outward motion cases. For the 31 speed graphs, there were 28 short-timescale change (5 and 10 epochs), 28 middle-timescale change (10 to 15 epochs) and 24 long-timescale change (15 to 20 epochs). Out of the 18 angle cases, there were 6 short-timescale change and 14 middle-timescale change and 12 long-timescale change.

I also looked at features within the same jet and compared their motion changes with each other. Although there were only two cases showed similarities, their extremely interesting characteristics might reveal what's happening inside the local jets.

The first case I found out was jet 0333+321 feature 6 and 7. [see Figure 5] Their speed vs epoch graphs had very strong match despite window sizes. And when looking at their radial motion graphs, they appear to be having very different motion changes at different epochs. However, we found out the places where the two features started slowing down were the same, 5 mas away from the jet source, despite the 5 epochs difference. This phenomenon gave us a reasonable theory that the jet itself has a stationary shock there and causes any feature goes through to bend. But more than that, what this case is telling us might just reveals a general or popular pattern of the intrinsic flow existing inside a jet itself. Thus, given the case I found out this summer, we should pay more attention on cases like jet 0333+321 and stationary shocks within in the future.

Works cited

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