Deep Stacking of AGN Hypervariables

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Gaussian Fits on J094511

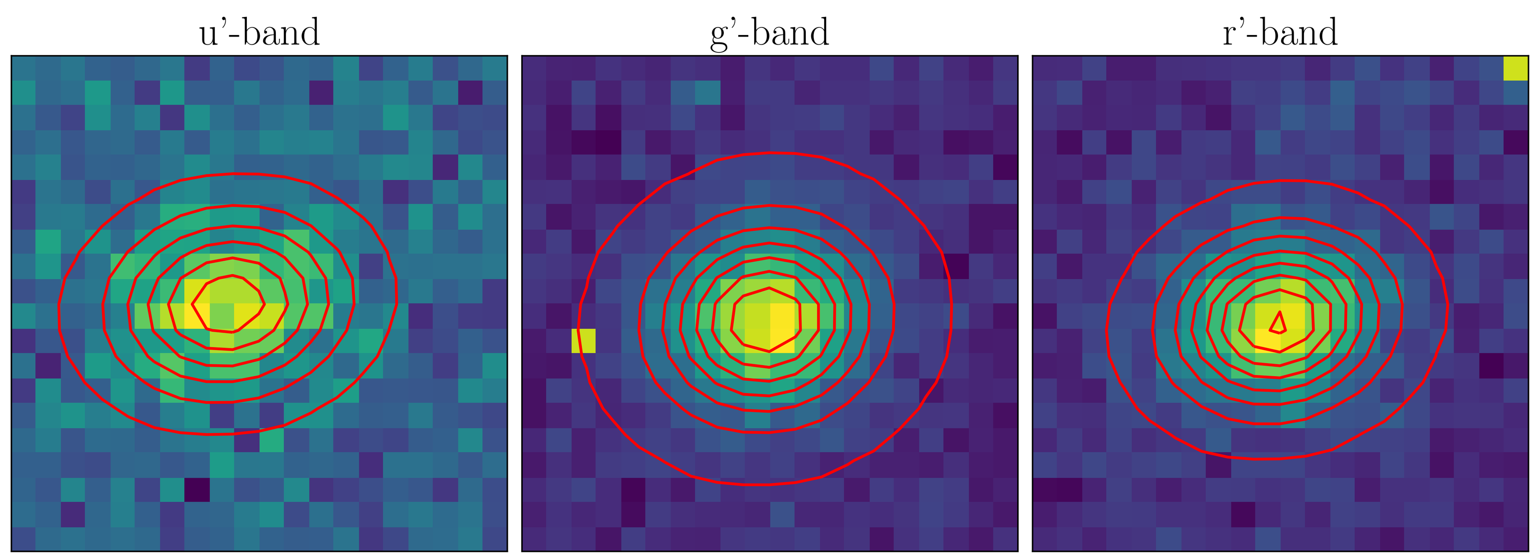

Figure 1. Gaussian fit on J094511 in the Sloan $u'g'r'$ bands.

A Faint Intervening Galaxy?

If the AGN is modeled as point source and intervening star modeled as a lens (simple microlensing model), it is possible to compute the lightcurve $F(t) = \mu(t)F_s$ which describes the evolution of the lensed AGN with respect to its unlensed flux, as described by Bruce et al. (2017).[1] If there is a diffuse but faint intervening source, there should be a flux contribution F_b from this source, measurable in the profile of J094511.

Extracting this profile from the existing Liverpool Telescope (LT) data is challenging. The object is very faint, with a low object to sky background ratio. Stacking many frames from the LT increases the signal to noise (S/N) ratio, but they must first be aligned.

WCS Alignment and Stacking

Using the World Coordinate System (WCS) data stored in FITS file headers, I have devised an algorithmic way to centroid on any object in a FITS file by specifying its known equatorial coordinates. Individual frames are then aligned to this point and stacked to increase the S/N ratio on that object. Once stacked, we can fit a Gaussian function to the resulting data to quantify the profile of the object (see Fig. 1).

Band	Amplitude	x_0	y_0	σ_x	σ_y	θ
u'	250(10)	8.2(2)	9.5(1)	0.83(4)″	0.64(3)″	0.2(1)
g'	2170(50)	9.34(6)	8.85(5)	0.75(2)″	0.66(2)″	0.2(1)
r'	2270(60)	9.37(7)	8.81(6)	0.75(2)″	0.60(2)″	0.02(1)

Table 1. Fitted Gaussian parameters for WCS based stacking.

This method, however, is limited to whole pixel resolution, and introduces several systematic uncertainties.

Abstract

In this project, I examine the unusual luminosity of the galactic nucleus SDSS J094511 located at redshift $z = 0.758$ using data gathered with the Liverpool Telescope on Las Palmas between 2012 and 2018. I develop several algorithms for centroiding on the object, for resampling to obtain higher resolution, and for stacking images to increase the S/N ratio in the frame. I extract radial and linear cross sections from the object and compare these to the point-spread-function of the Liverpool Telescope CCD to corroborate the hypothesis that linear increases in the luminosity over large timescales are *not* due to instability of the viscous AGN accretion disk, but a gravitational microlensing event by a star in an intervening galaxy or dwarf galaxy.

What are Hypervariable AGN?

Active galactic nuclei (AGN) are variably luminous, deep sky objects. The source of their luminosity is widely believed to be the accretion of matter into a disk around supermassive black holes.[3] The accretion disk model explains many of their observed properties, including:

- Luminous and compact appearance
- Broad spectrum energy emission
- Variable over short timescales

But Lawrence et al. (2016) identify several slowly evolving, blue "hypervariable" AGN, which increase and decrease smoothly by several magnitudes over a period of years. One such hypervariable AGN is SDSS J094511. These are not compatible with the AGN accretion disk model, and they propose that gravitational lensing events are responsible for variable luminosity in these objects.[2]

Radial Profiles of J094511

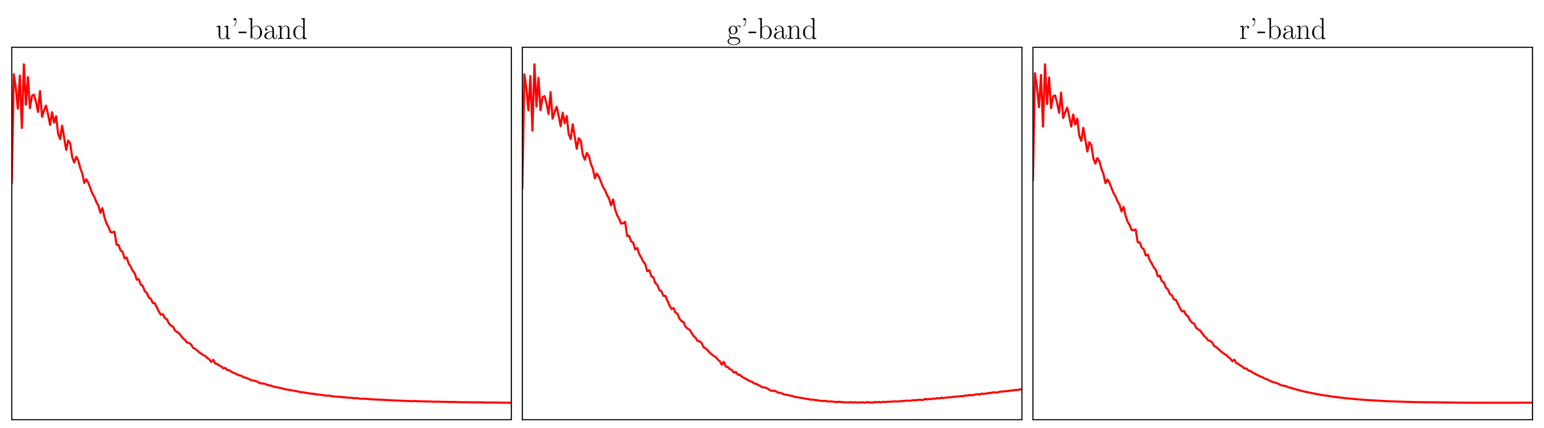

Figure 2. Radial profile of J094511 in the Sloan $u'g'r'$ bands.

The radial profiles of J094511 are Gaussian in form. By training the algorithm an intragralactic point source, it is possible to obtain the point-spread-function (PSF) response of the LT, and subtract this from the profile of J094511 to obtain a profile of the intervening galaxy, the area integral of which is F_b.

Gaussian Resampling of J094511

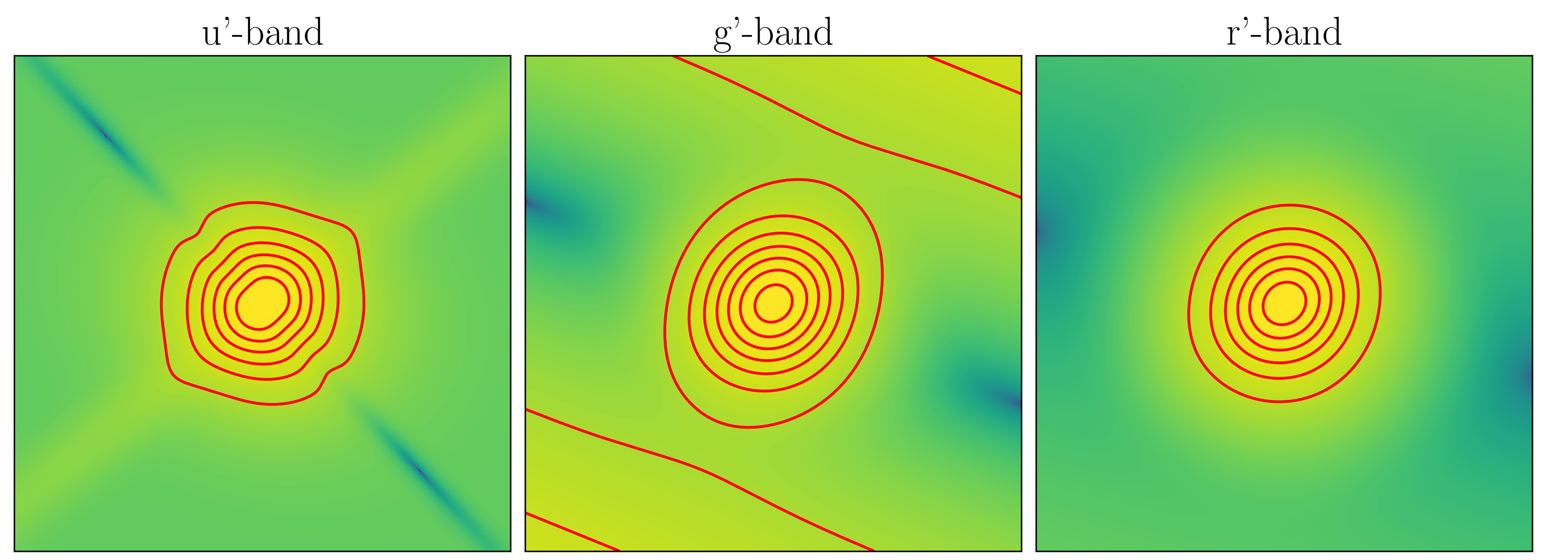

Figure 3. Resampled stacks of J094511 in the Sloan $u'g'r'$ bands.

Gaussian Resampling for Higher Resolution

By fitting a Gaussian function to individual frames, though, we can interpolate the flux at non-integer pixel values. The fitted function has "infinite" resolution; and by aligning and summing these fitted forms, we can obtain a high S/N ratio for the object at any desired resolution. Once again, fitting a Gaussian function to the resulting stack allows us to quantify the object profile.

Band	Amplitude	x_0	y_0	σ_x	σ_y	θ
u'	385.42(5)	499.5	499.5	0.568″	0.525″	0.689
g'	2889.0(2)	499.5	499.5	0.611″	0.557″	3.969
r'	3168.9(2)	499.5	499.5	0.529″	0.579″	2.472

Table 2. Fitted Gaussian parameters for resampled stacking.

The parameters in Table 2 are fitted to a resampled image with 50x the resolution of the LT frames. The uncertainties on these parameters are trivially small, unless listed. Another algorithm was devised to extract the radial profiles in Fig. 2 by summing the counts in annuli placed around the object.

All of these algorithms are open source and licensed under GNU GPLv3 License, are free to use, and have wide applications in computational astronomy.

References

[1]A. Bruce, A. Lawrence, C. MacLeod, M. Elvis, M. J. Ward, J. S. Collinson, S. Gezari, P. J. Marshall, M. C. Lam, R. Kotak, C. Inserra, J. Polshaw, N. Kaiser, R.-P. Kudritzki, E. A. Magnier, and C. Waters, "Spectral analysis of four 'hypervariable' agn: a microneedle in the haystack?", Monthly Notices of the Royal Astronomical Society **467**, 1259–1280 (2017).

[2]A. Lawrence, A. G. Bruce, C. MacLeod, S. Gezari, M. Elvis, M. Ward, S. J. Smartt, K. W. Smith, D. Wright, M. Fraser, P. Marshall, N. Kaiser, W. Burgett, E. Magnier, J. Tonry, K. Chambers, R. Wainscoat, C. Waters, P. Price, N. Metcalfe, S. Valenti, R. Kotak, A. Mead, C. Inserra, T. W. Chen, and A. Soderberg, "Slow-blue nuclear hypervariables in panstarrs-1", Monthly Notices of the Royal Astronomical Society **463**, 296–331 (2016).

[3]A. Lawrence, "Quasar viscosity crisis", eng, Nat Astron **2**, 102–103.