VLBI detection of refractive scattering in the quasar 2005+403

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Analyzing scattering properties of the interstellar medium of the Galaxy based on VLBI observations of about 9 000 AGN jets at frequencies ranging from 1.4 to 86 GHz (Koryukova et al. 2022, MNRAS, accepted), we have identified a very limited number of sources, including the quasar 2005+403, that show anisotropic refractive-dominated scattering.

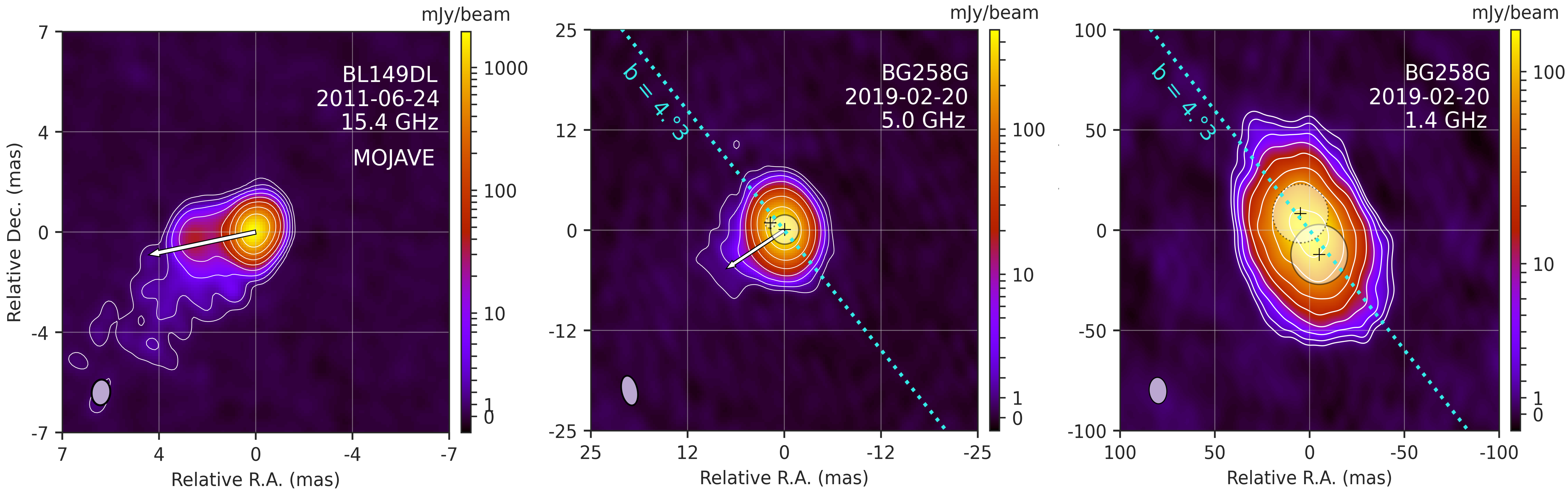

Figure 1: VLBA images of 2005+403. Left: 15.4 GHz map with the inner jet PA ≈ 100° (white arrow). Middle: 5.0 GHz map with the jet PA ≈ 124° (white arrow). Right: 1.4 GHz map. The scatter-induced pattern is extended along the line of constant Galactic latitude (b = 4°.3) at PA ≈ 40° (cyan dotted line). The contours are plotted at increasing power of 2, starting from the corresponding 4 rms level. Shaded circles represent the fitted Gaussian components of the core (brightest feature, solid line circle) and its sub-image (dotted line circle).

1. Multiple imaging. The secondary images can be induced by lensing effect when a plasma lens with a Gaussian profile of free-electron column density passes between the observer and a background radio source (Clegg et al. 1998). Their relative motion might produce caustic surfaces and split the source to the hierarchy of multiple sub-images.

At relatively high frequency 15.4 GHz (Fig. 1, left), the source is not subject to scattering and shows a typical core-jet morphology. At lower frequency, 5.0 GHz (Fig. 1, middle), we detect a scattered secondary sub-image of the core, while the jet propagating along PA ≈ 124° is still seen. At the lowest frequency, 1.4 GHz (Fig. 1, right), the observed morphology is clearly scatter-dominated. The secondary core image detected at 1.4 and 5.0 GHz is shifted along the line of constant Galactic latitude b = 4°.3 at PA ≈ 40°, which indicates the orbital motion of a plasma lens in the Galaxy. The refractive power of the lens is high enough to separate the secondary core image from its primary one.

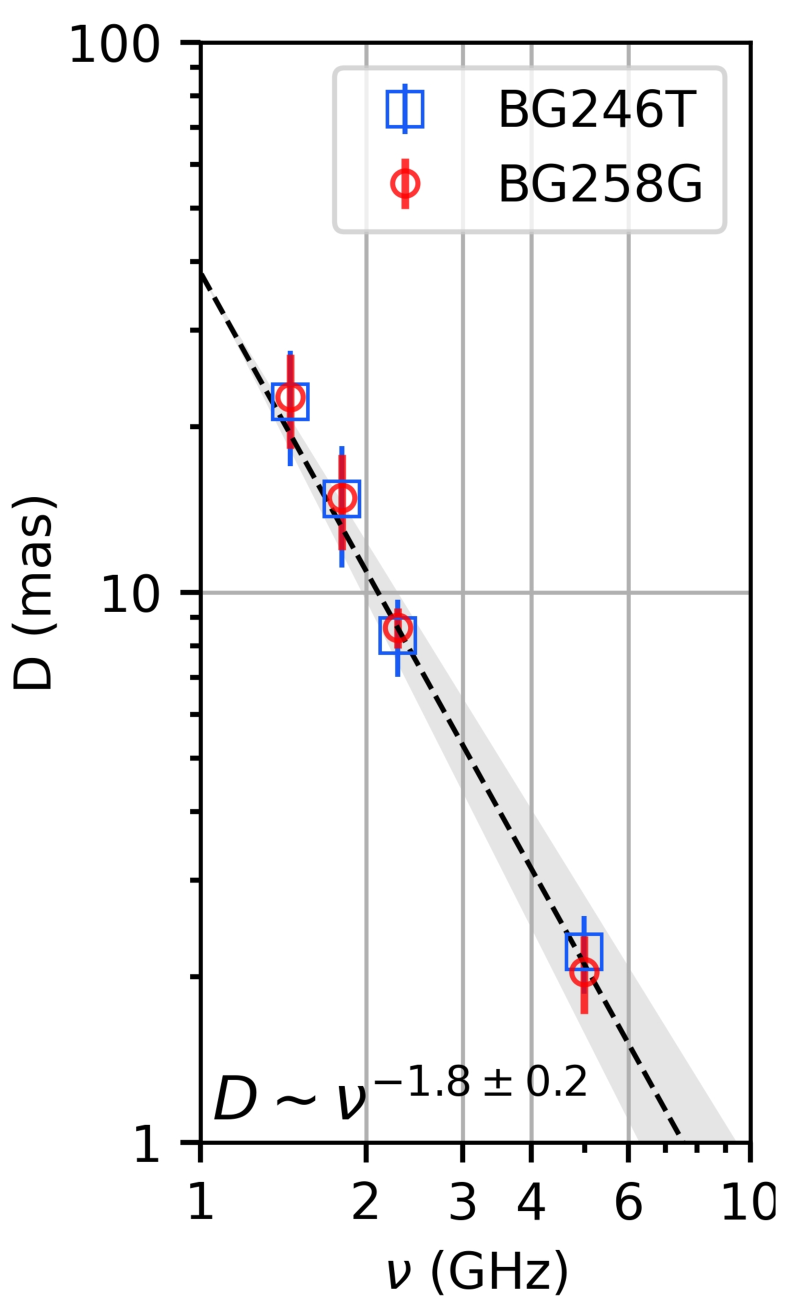

Figure 2: Distance between the core component and its secondary image as a function of observing frequency.

2. Modeling of structure. We fitted the observed brightness distributions at 1.4, 1.8, 2.3 and 5.0 GHz with circular Gaussian components. The best fit models contain three components at 2.3 and 5.0 GHz, and two components at 1.4 and 1.8 GHz. We derived the distance D between the core component and its secondary image induced by refractive scattering and shifted along the line of constant Galactic latitude. This distance depends on the frequency with a power of –1.8 ± 0.2 (Fig. 2). The estimated distance error was used as weight for fitting. Fitting without weights yields –1.9 ± 0.1. Scaling D close to ν^{-2} is a direct observational evidence of the scattering screen with electron density profile close to Gaussian.

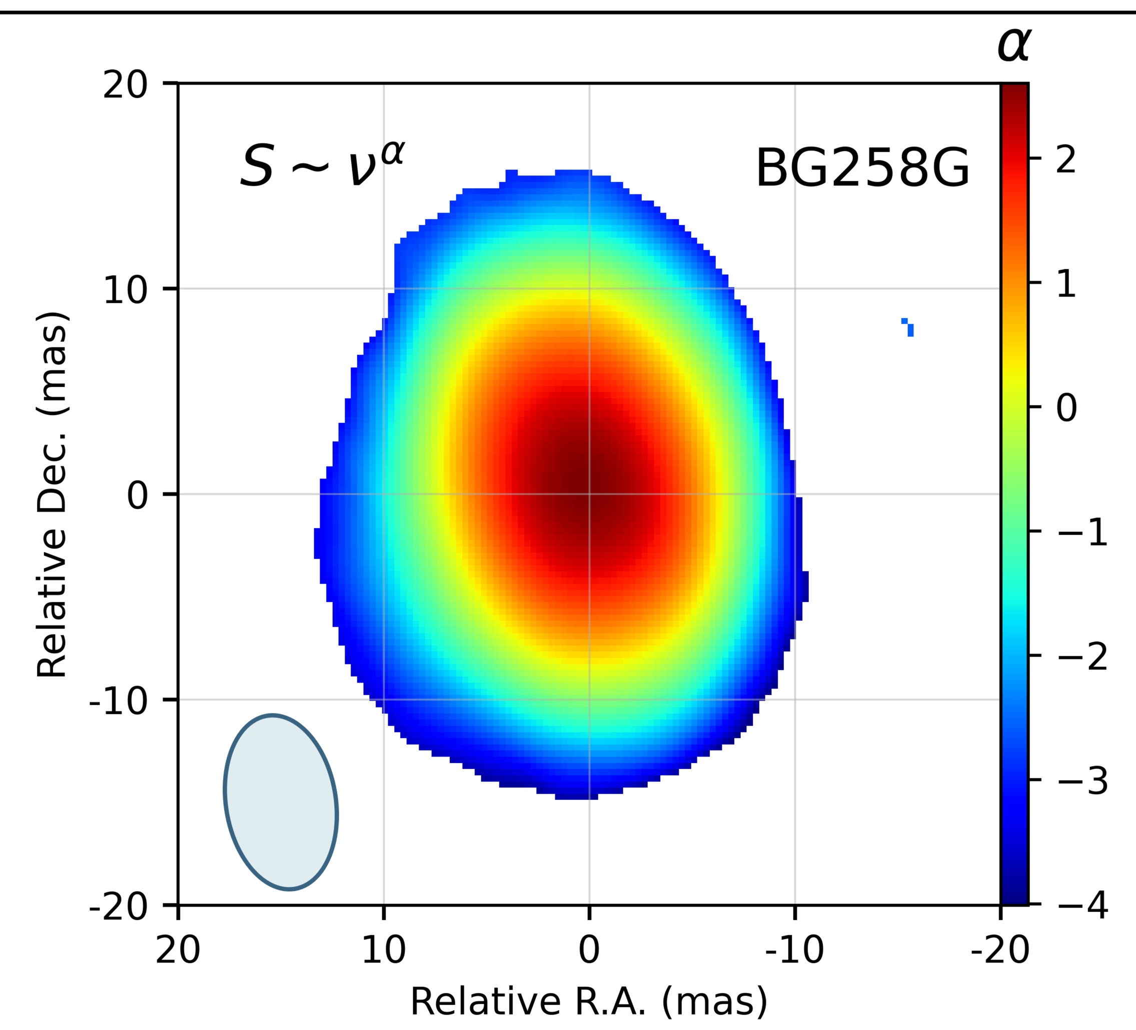

Figure 3: Spectral index distribution, derived using simultaneous 1.4 and 5.0 GHz data convolved with the average restoring beam, FWHM of which is shown by the light gray ellipse.

3. Spectral index distribution. We have made the spectral index distribution using the simultaneous 1.4 and 5.0 GHz data aligning the maps by the core component position. The obtained extreme values of the spectral index are caused by a progressively stronger scattering at lower frequencies.

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