Radio Jet Interactions in the Interstellar Medium of an Extreme Radio-loud Quasar in the first Gyr of the Universe

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I investigate P352—15, one of the most powerful radio sources known near the end of the Epoch of Reionization at redshift z=5.832 (age of the universe 948 Myr). This quasar is the only one at these high redshifts with direct evidence of powerful and extended (~1.6 kpc) radio jets (Fig. 1), which allows us to test for the first time whether the radio lobes affect the dust and gas during the formation of a massive galaxy within the first billion years of the universe (Rojas-Ruiz et al. submitted to ApJ).

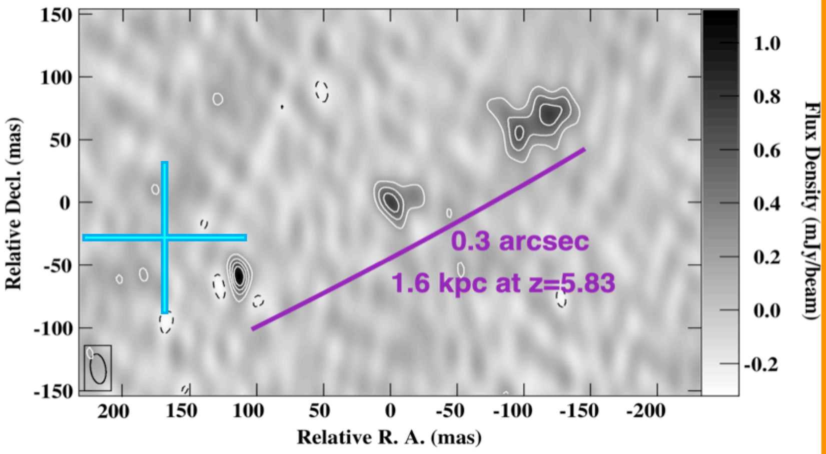

Figure 1. High-resolution VLBA image of radio lobes in P352—15 (Momjian et al. 2018). The cross indicates the optical position of the quasar.

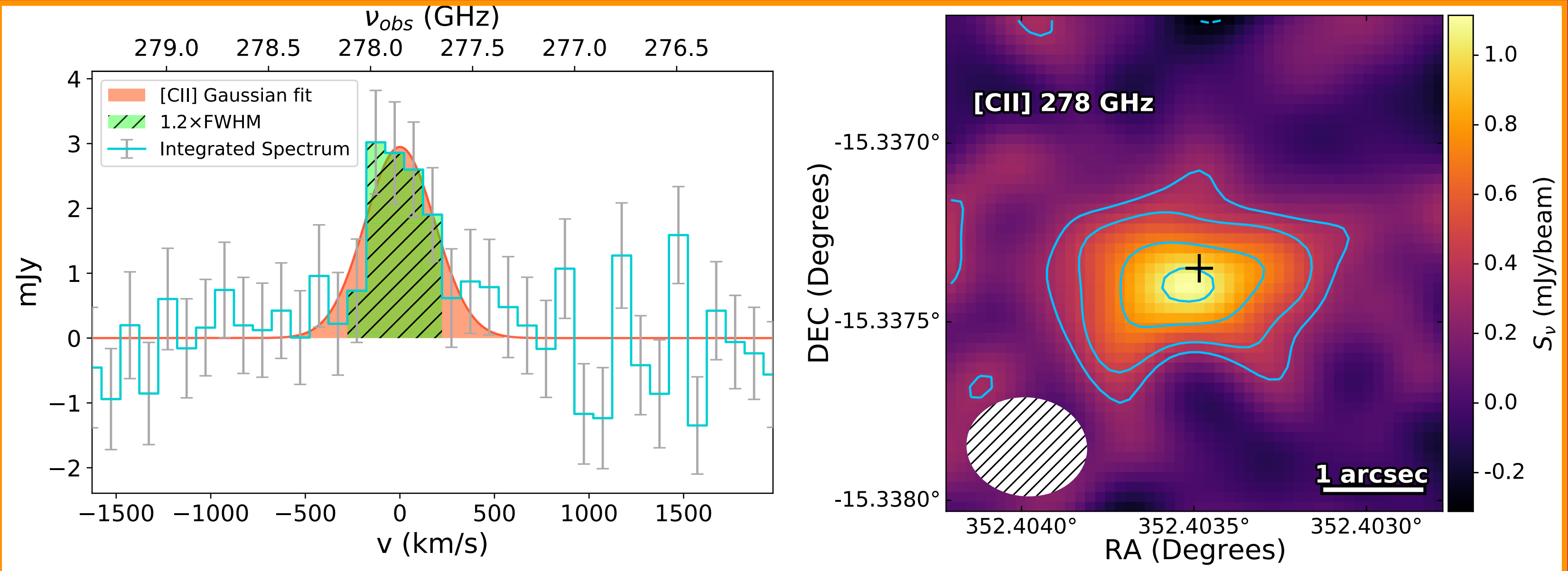

Figure 2. *Left:* Analysis of the ALMA mm data showing a broad [CII] line peaking at 2.78±0.45 mJy from which we measure a systemic redshift of z = 5.832±0.001. *Right:* 2D map of the marginally resolved [CII] emission detected at S/N > 7.5. The contour levels are shown at (2, 3, 5, 7) σ where the Beam is 1.3" × 1.0".

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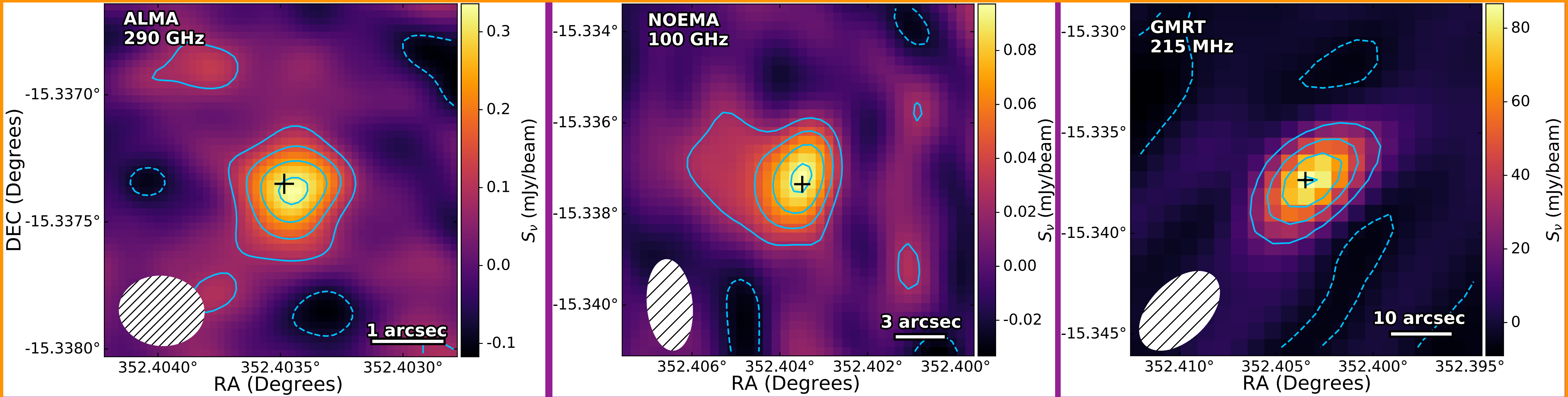

Figure 3. *Left:* ALMA 290 GHz continuum emission map with flux density 0.34±0.04 mJy and beam size 1.3" × 1.0". *Middle:* NOEMA 100 GHz continuum emission map with flux density 0.10±0.01 mJy, the beam size is 7.3" × 3.7". *Right:* GMRT 215 MHz emission map with flux density 88±7 mJy and beam size of 18" × 11". The contour levels for ALMA and NOEMA maps are shown at (-2, 2, 4, 6, 8)σ and both have S/N > 8. The GMRT continuum has contours shown at (-1, 5, 10, 15, 20)σ and has S/N > 20. For all maps, the quasar appears unresolved, the dashed (solid) contours represent the negative (positive) σ, respectively. The cross in all panels indicates the optical position of P352—15 from Momjian et al. 2018 with the errors increased for visualization.

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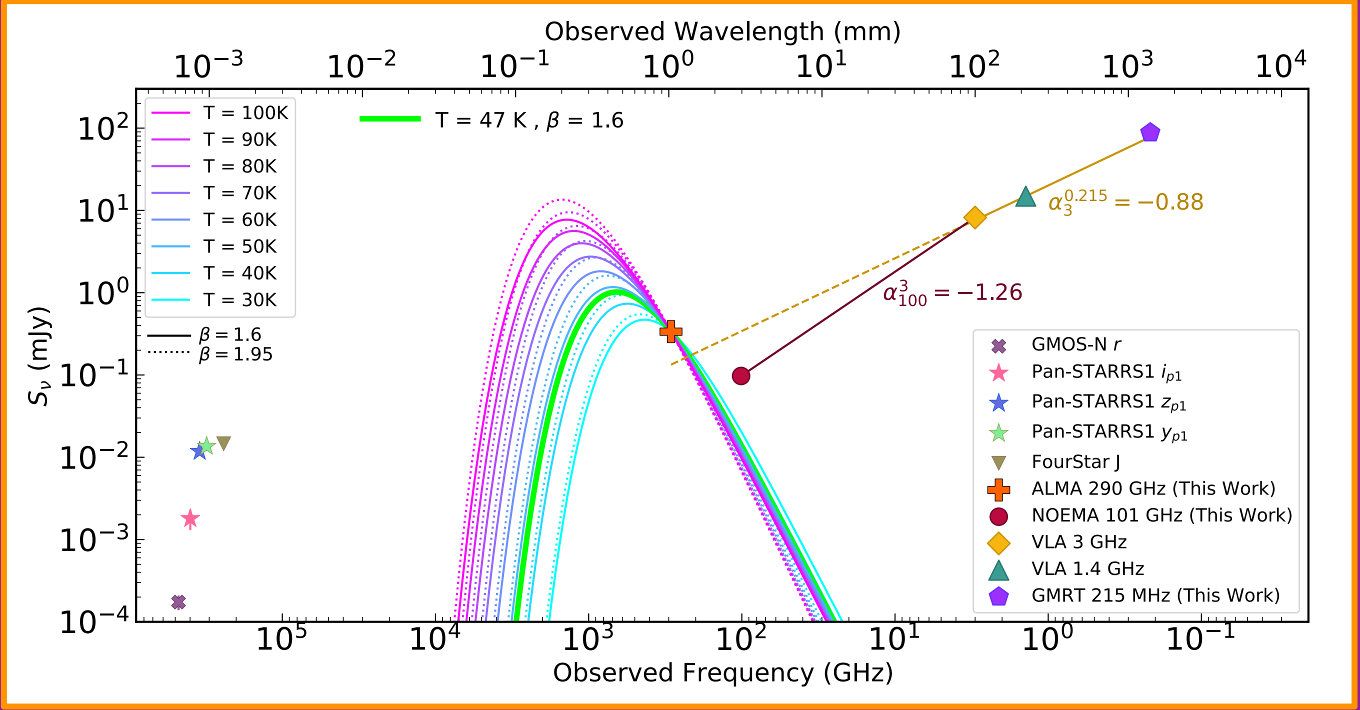

Figure 4. The new GMRT measurement presented here along with the previous VLA 1.4 and 3 GHz radio observations of this quasar are consistent with synchrotron emission following a power law ($f_\nu \propto \nu^\alpha$) with slope α = -0.88. The mm points require more careful analysis.

To investigate the dust emission, I show a modified black-body (MBB) after correcting for CMB contrast for a range of temperatures (30K - 100K), and using the most accepted values of the dust emissivity spectral index for high-redshift quasars $\beta = 1.95$ and $\beta = 1.6$. None of these MBBs fit for the NOEMA flux measurement we calculate. In fact, this measurement has to be dominated by synchrotron emission and dust, if any.

Therefore, we conclude that the radio jets are indeed affecting the continuum emission from the host galaxy of P352—15.

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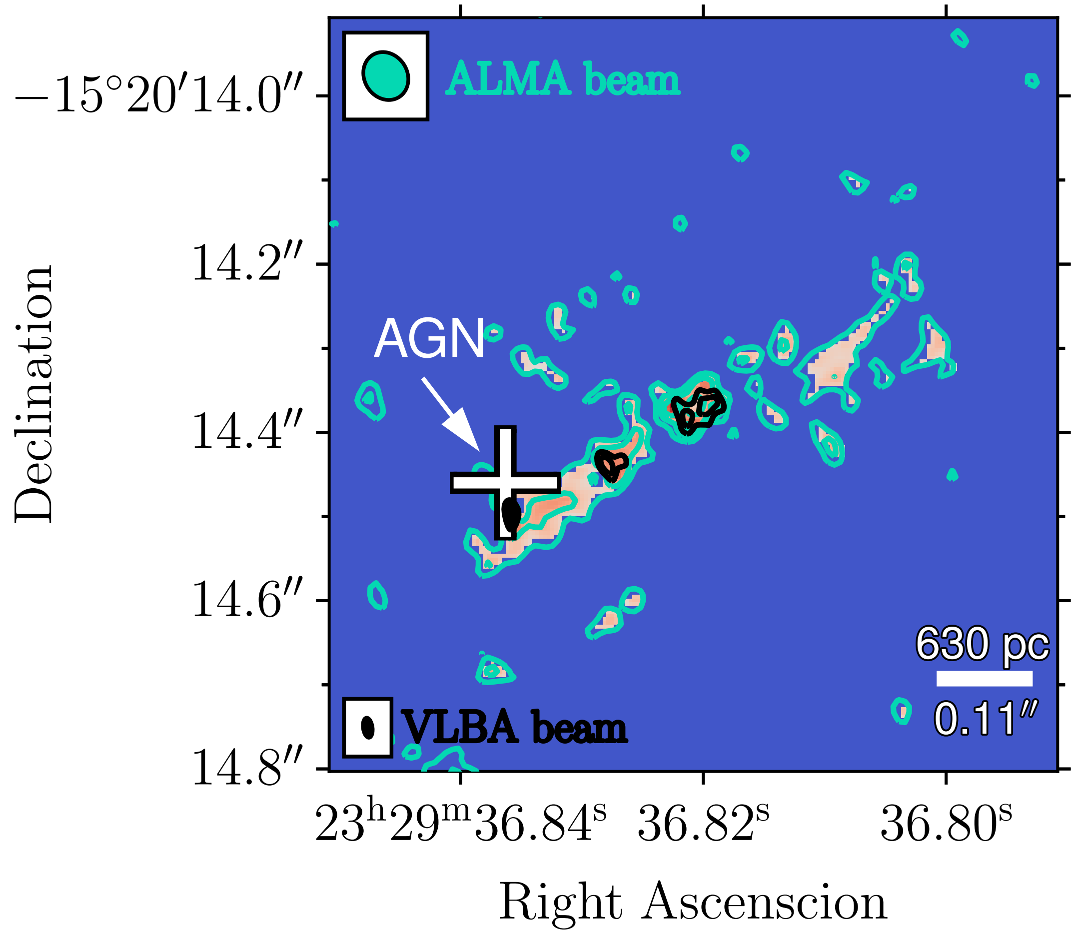

Figure 5. ALMA 278 GHz high-resolution [CII] map of P352–15 (image with green contours). The white cross shows the optical position from the quasar.

The black contours represent the VLBA 1.54 GHz emission reported by Momjian et al. 2018 (Fig. 1). Here the [CII] emission is evidently aligned in the same direction of the radio jet.

There is tantalising evidence of a [CII] radio-driven outflow. However, the current S/N is ~2-4 per beam and higher S/N data are required to model the dynamics of the outflow and its effect on the host galaxy.