THE JET COLLIMATION PROFILE AT HIGH RESOLUTION IN BL LACERTAE

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C. CASADIO ET AL., 2021, A&A, 649, A153

CONTEXT: Controversial studies on the jet collimation profile of BL Lacertae (BL Lac), the eponymous blazar of BL Lac objects class, complicate the scenario in this already puzzling class of objects. Understanding the jet geometry, in connection with the jet kinematics and the physical conditions in the surrounding medium, is fundamental to better constrain the formation, acceleration and collimation mechanisms in extragalactic jets.

AIMS: With the aim of investigating the jet geometry in the innermost regions of the jet of BL Lac, and solving the controversy, we explore the radio jet in this source, using high resolution millimeter-wave Very Long Baseline Interferometric (VLBI) data.

METHODS: We collect 86 GHz GMVA and 43 GHz VLBA data to obtain stacked images that we use to infer the jet collimation profile by means of two comparable methods. We analyze the kinematics at 86 GHz, and we discuss it in the context of the jet expansion. Finally we consider a possible implication of the Bondi sphere in shaping the different expanding region observed along the jet.

RESULTS: The jet in BL Lac expands with an overall conical geometry. A higher expanding rate region is observed between ~ 5 and 10 pc (de-projected) from the black hole. Such a region is associated with the decrease in brightness usually observed in high- frequency VLBI images of BL Lac. The jet retrieves the original jet expansion around 17 pc, where the presence of a recollimation shock is supported by both the jet profile and the 15 GHz kinematics (MOJAVE survey). The change in the jet expansion profile occur- ring at ~ 5 pc could be associated with a change in the external pressure profile in correspondence of the Bondi radius ($\sim 3.3 \times 10^5 R_S$).

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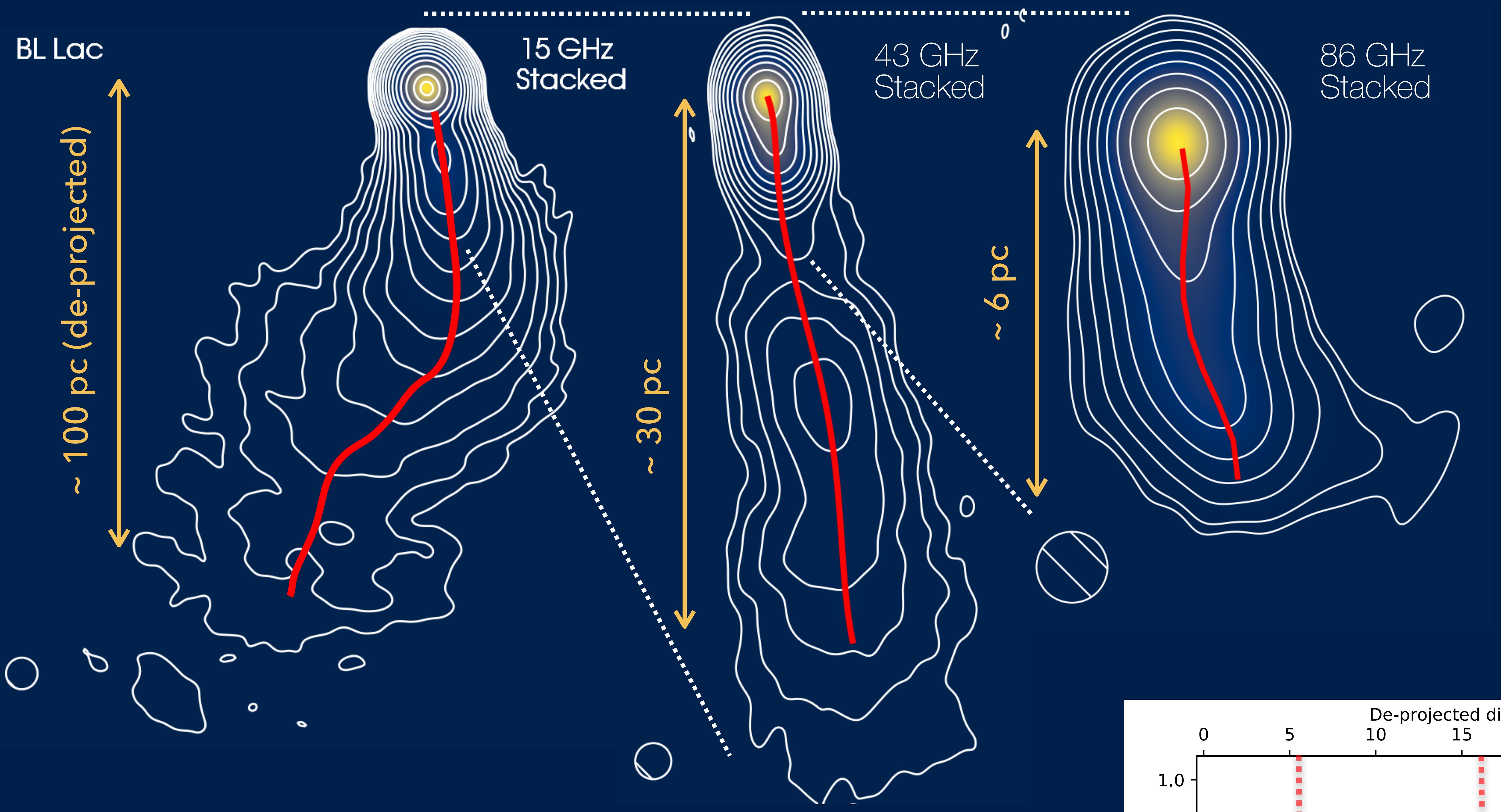
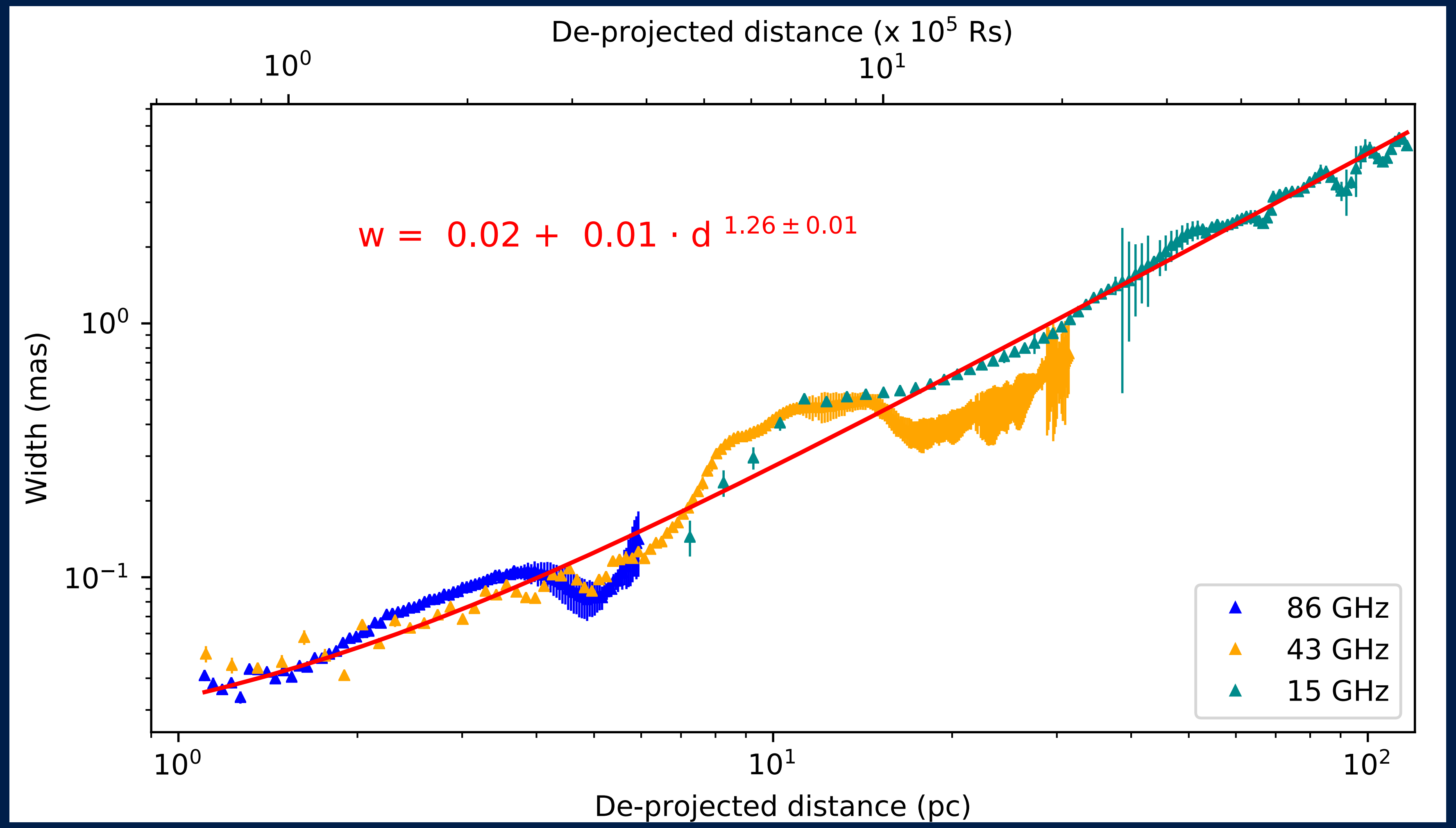
THE IMPORTANCE OF HIGH RESOLUTION





From the mm-core (~ 1 pc from the BH, 0.6 x $10^5 R_S$, Marscher et al. 2008) up to ~ 100 pc, the jet expands CONICALLY.

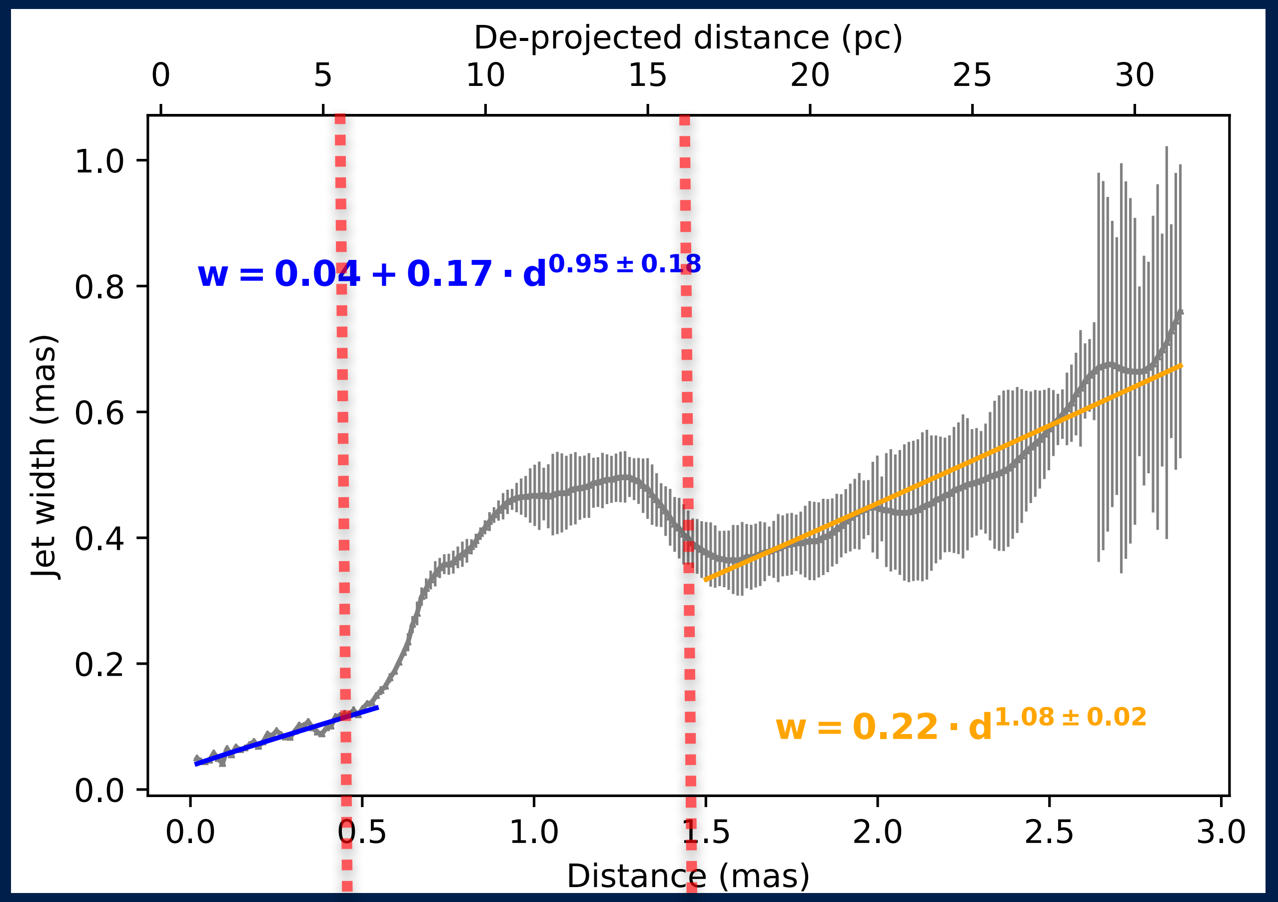
15 GHz: MOJAVE (Pushkarev et al., 2017)

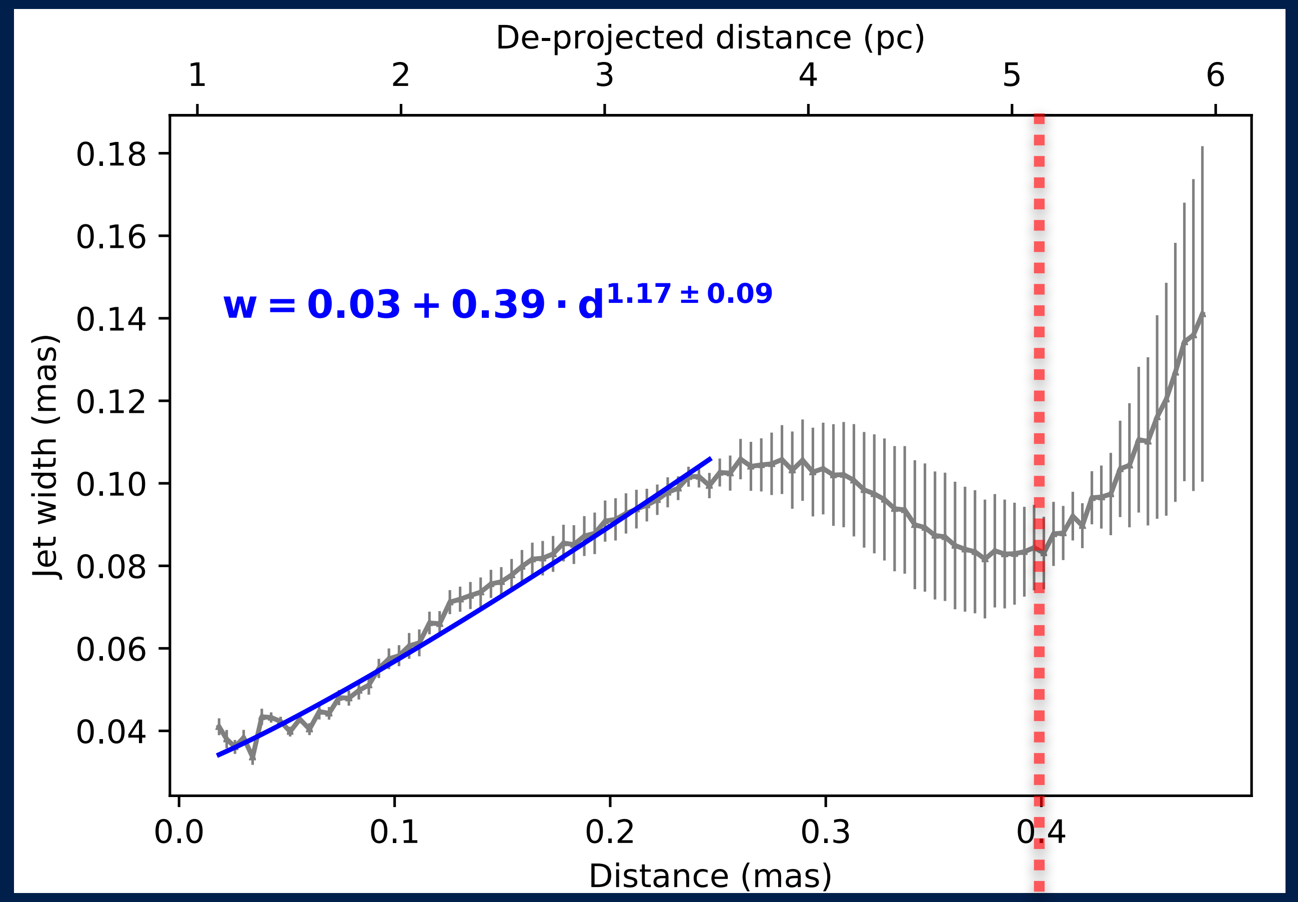
43 GHz: VLBA-BU-BLAZAR

(94 epochs, May 2009 - March 2019)

86 GHz: GMVA

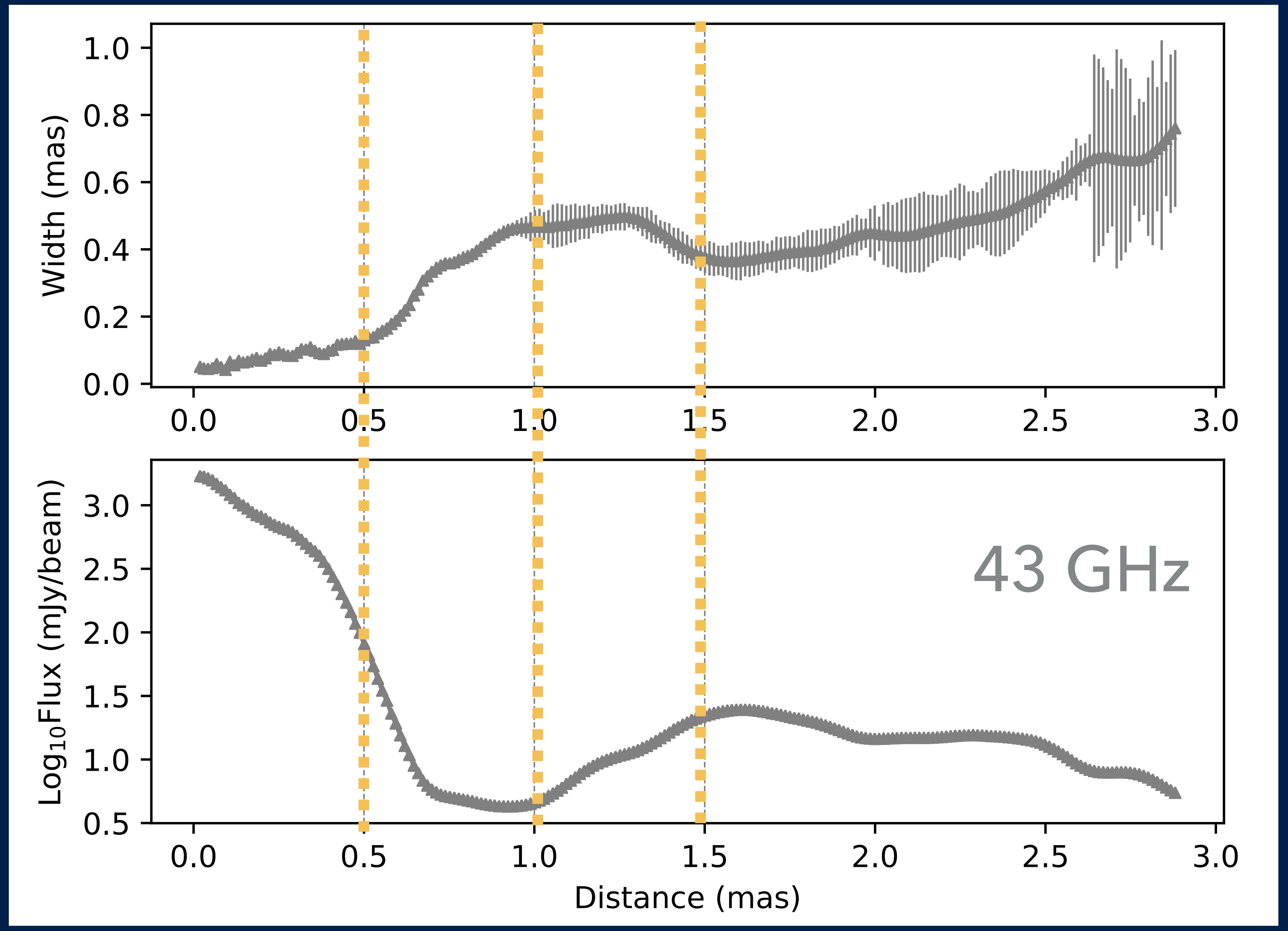
(11 epochs, May 2009 - April 2017)



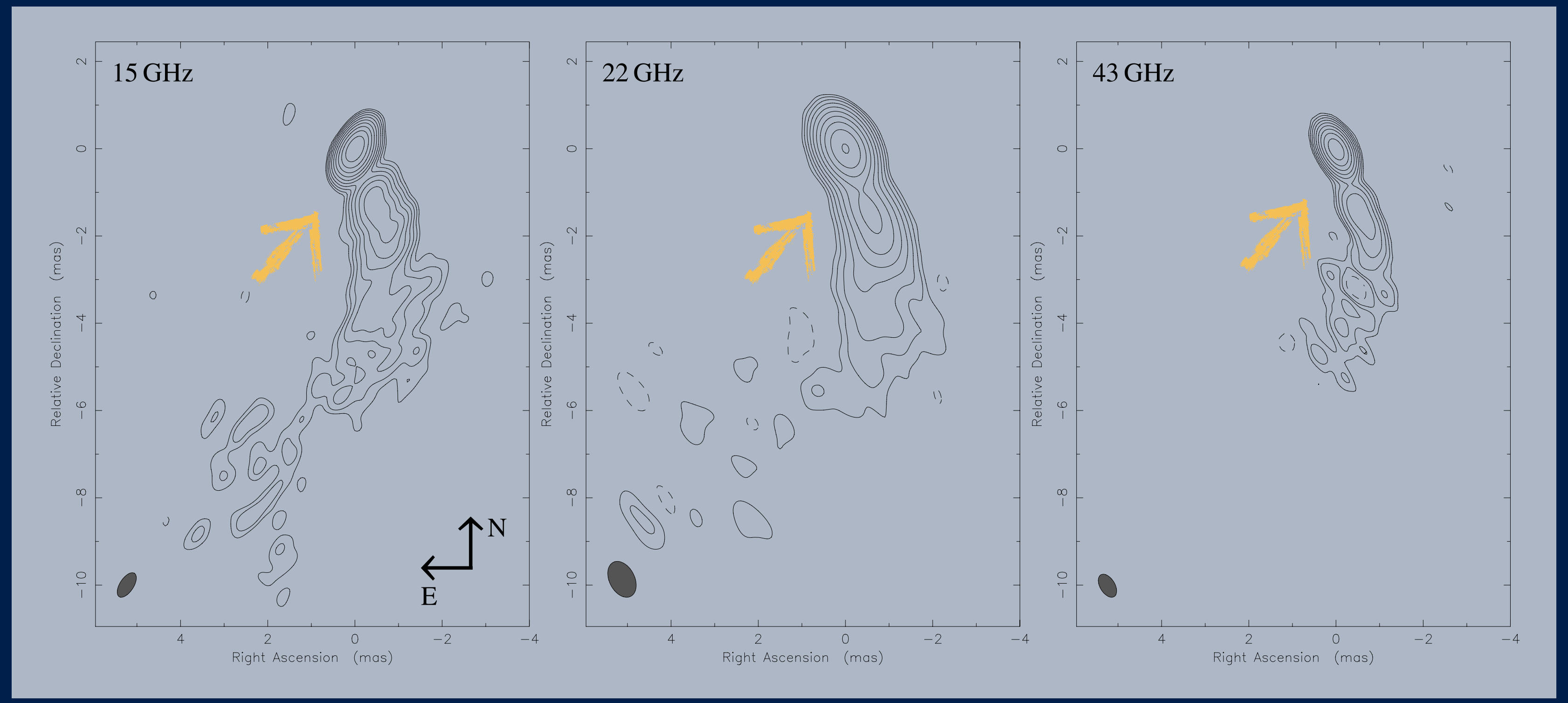


The higher resolution of the 43 and 86 GHz data reveals a higher expanding rate region between ~ 5 and ~ 10 pc, followed by a recollimation of the jet (~ 17 pc) and the restart of the jet expansion with the same initial rate

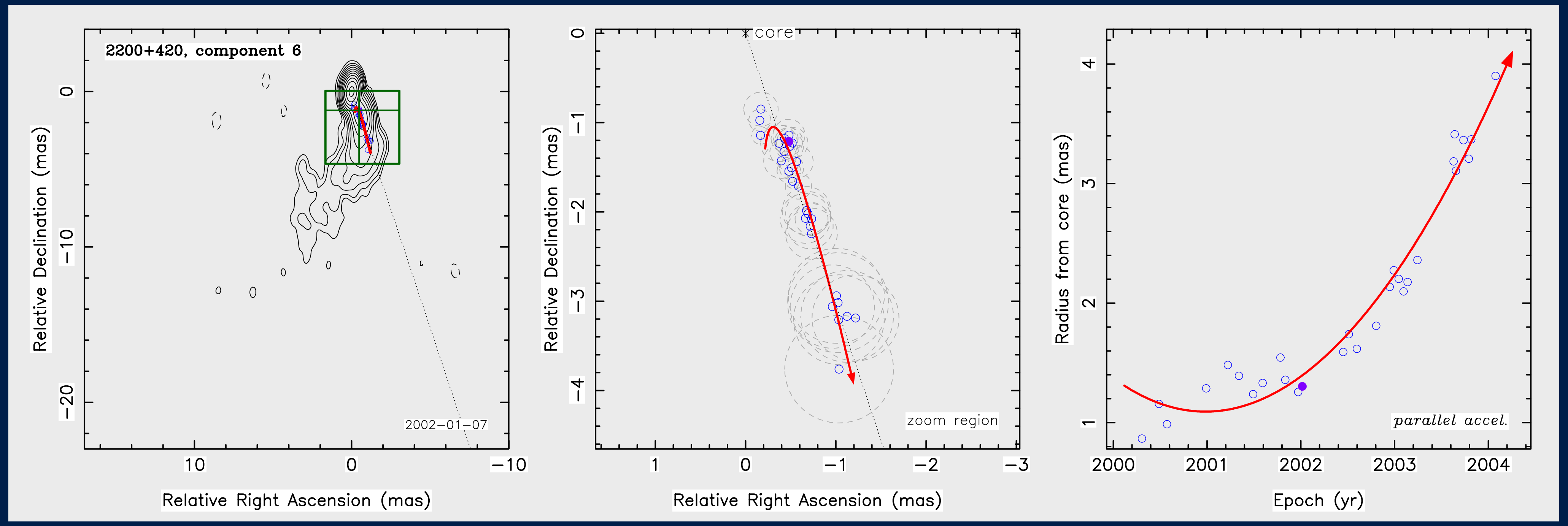
WHO IS THE RESPONSIBLE FOR THE SUDDEN JET WIDENING?



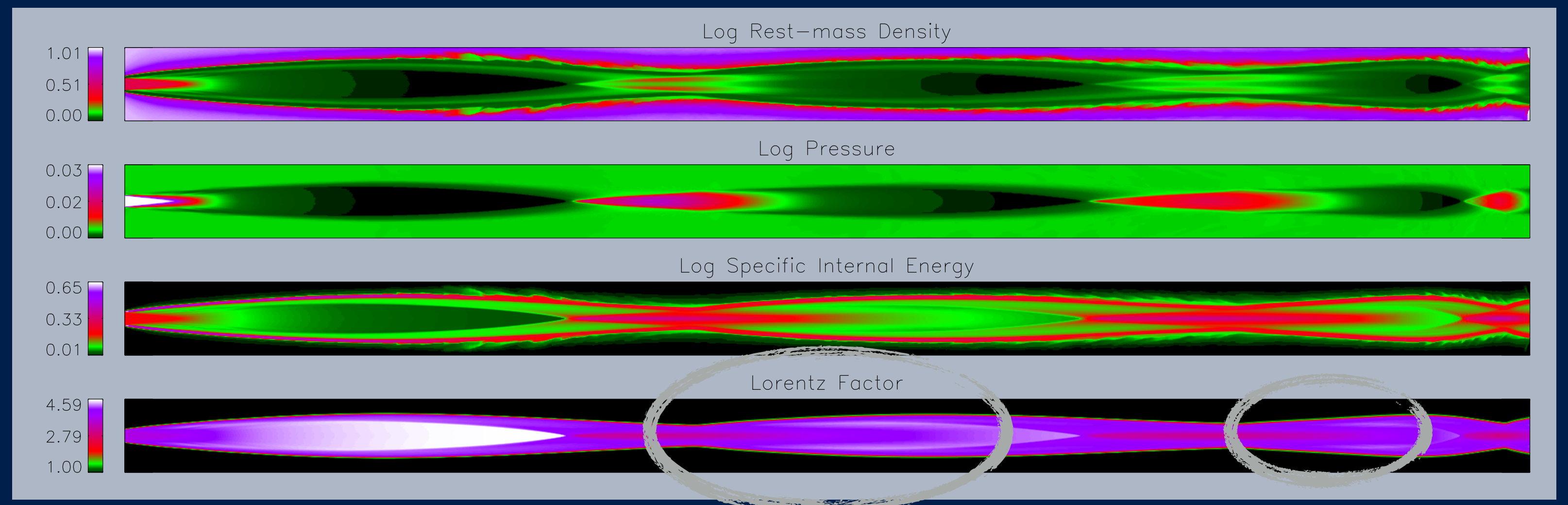
The higher expanding rate region and associated adiabatic losses and decrease in magnetic field strength naturally explain the low emission region around 0.7 - 1 mas from the core usually observed in high frequency VLBI images



(Bach et al., 2006)



15 GHz model fits components (MOJAVE kinematics) show acceleration parallel to the velocity vector starting from ~1 - 1.5 mas, as expected in the region after a recollimation shock.



RHD simulation of a jet with an initial over-pressure 10 times larger than the external medium, leading to a set of recollimation shocks.
Reproduced from Casadio et al., 2013.

http://www.physics.purdue.edu/astro/MOJAVE/velocitytableXVIII.html

CONCLUSIONS

- The jet expands with an overall conical geometry;
- The overall jet expansion is interrupted by a different expanding region between ~ 5 pc and 17 pc (de-projected) from the black holes (BH), where the jet expands faster and then it recollimates. The higher expansion rate is accompanied by a severe decrease in brightness explained considering adiabatic cooling being the main energy loss mechanism there. The jet recollimation, which occurs at around 17 pc downstream, is instead associated with an increase in flux density, explained either by particle re-acceleration or by a local increase in particle density;
- The change in the jet expansion profile could be associated with a change in the external pressure profile occurring where the BH ceases its gravitational influence on the surrounding material, at the Bondi radius ($\sim 3.3\times10^{5} R_S$) - see calculation in the paper;
- Both the kinematics and the collimation profile at 3 mm, support the existence of a stationary recollimation shock just before the jet starts expanding faster. The location coincides with the recollimation shock observed at 15 GHz within the MOJAVE survey (Cohen et al. 2014, 2015; Arshakian et al. 2020);
- The parallel acceleration displayed by some model-fit components at 15 GHz (MOJAVE survey) after ~1 mas (11 pc), is in agreement with the jet physical conditions downstream a recollimation shock, as predicted by numerical simulations (e.g., Mizuno et al. 2015). This could prove the existence of a recollimation shock around 17 pc, as already observed in the jet expansion profile and supported by the radial flux density profile.

Conference fee covered by the "2020 Galaxies Travel Award" sponsored by the open access journal Galaxies published by MDPI.

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