Total and Linearly Polarized Synchrotron Emission from Overpressured Magnetized Relativistic Jets

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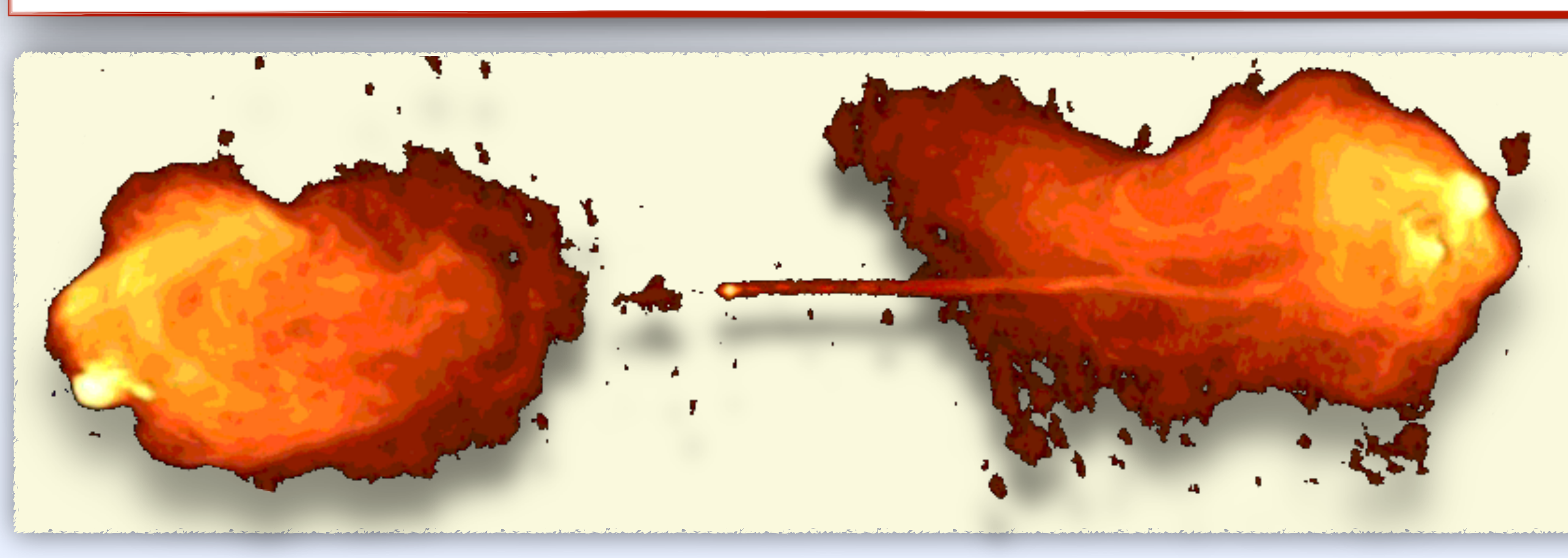
Abstract We present relativistic magnetohydrodynamic (RMHD) simulations of stationary overpressured magnetized relativistic jets, which are characterized by their dominant type of energy: internal, kinetic, or magnetic. Each model is threaded by a helical magnetic field and features a series of recollimation shocks produced by the pressure mismatch between the jet and the ambient medium. We study the polarization signatures from these models by integrating the radiative transfer equations for synchrotron radiation using as inputs the RMHD solutions. These simulations show a top-down emission asymmetry produced by the helical magnetic field and a progressive confinement of the emission into a jet spine as the magnetization increases. Bright stationary knots associated with the recollimation shocks appear, presenting a relative intensity modulated by differential Doppler boosting. Small viewing angles show a bimodal distribution in the polarization angle due to the helical structure of the magnetic field, which is also responsible for the highly stratified degree of linear polarization across the jet width. In addition, small variations of the order of 26° are observed in the polarization angle of the stationary components, which can be used to identify recollimation shocks in astrophysical jets.



Context Active Galactic Nuclei (AGNs) jets are highly collimated plasma outflows launched by helical magnetic fields from either the acretion disk or the supermassive black hole's ergosphere. Particles composing the jet plasma travel at relativistic speeds radiating all across the electromagnetic spectrum, and up to megaparsec distances when the interaction with the intergalactic medium creates hotspots. Very Long Baseline Interferometry (VLBI) observations often reveal superluminal motion, due to projection effects, of bright knots along the jet. However, some of this knots appear to remain stationary through the years. Which mechanism is producing these stationary bright components is still an open question. We address their nature in the context of a recollimating jet in **Fuentes et al. 2018, ApJ, 860, 121**.

Code

RMHD code Solves the relativistic magnetohydrodynamic equations in conservation form for an ideal gas equation of state, being:

- 2.5D axially symmetric
- Second-order
- Conservative
- Finite-volume
- Based on high-resolution shock-capturing techniques

- Parameters characterizing the models:
  - Jet density
  - Axial velocity
  - Overpressure factor
  - Mach number
  - Magnetization
  - Pitch angle

- Refs: Martí 2015a, CoPhC, 191, 100; Martí 2015b, MNRAS, 452, 3106; Martí+ 2016, ApJ, 831, 163; Komissarov+ 2015, ComAC, 2, 9

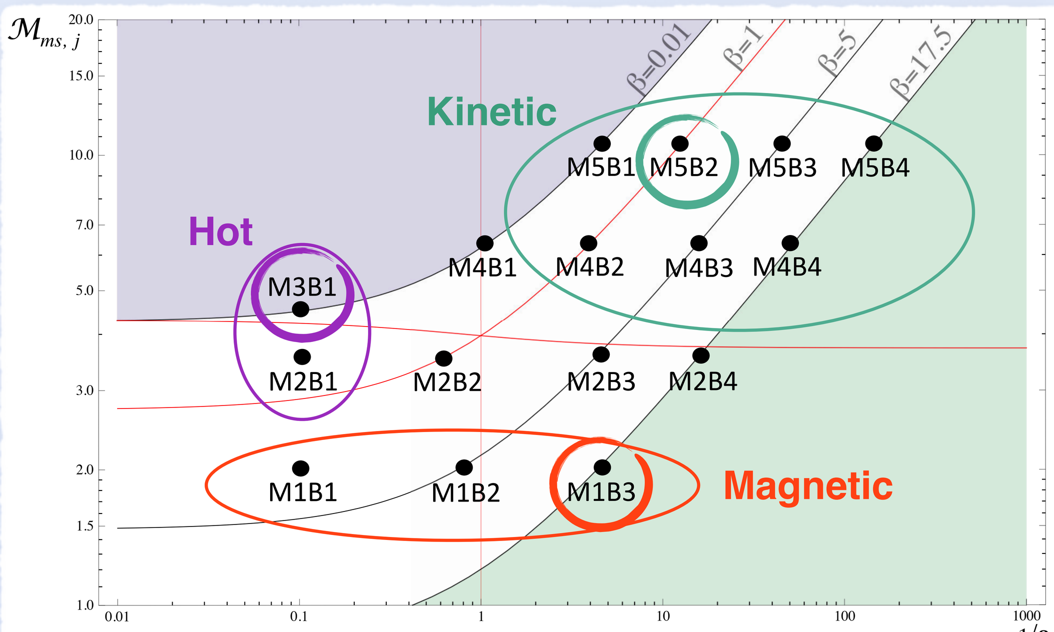


Fig 1. Mach number vs specific internal energy for different levels of magnetization.

Emission code Solves the radiative transfer equations for synchrotron radiation:

- Using RMHD inputs
- Assuming a power law energy distribution
- Obtains the Stokes parameters I, Q, U, V(=0)
- Accounts for relativistic effects:
  - Lorentz transformations
  - Doppler boosting
  - Light aberration
- Refs: Gómez+ 1995, ApJL, 449, L19; Gómez+ 1997, ApJL, 482, L33

Results

Internal Structure

- Jet models are classified in three regions (see Fig. 1) depending on their dominant type of energy: internal (hot), magnetic, and kinetic.
- The pressure mismatch between the jet and the ambient medium leads to the formation of a pattern of conical Recollimation Shocks (RSs), see Fig. 2.
- The internal structure is mainly governed by the Mach number and, to a less extent, by the internal energy and magnetization. These last two determine the RSs' strength and the jets' transversal shape, respectively.
- RSs produce bright stationary knots (Fig. 2, right panel), more intense for kinetic jets at small viewing angles, while hot and magnetic jets present more intense knots at larger viewing angles due to differential Doppler boosting.

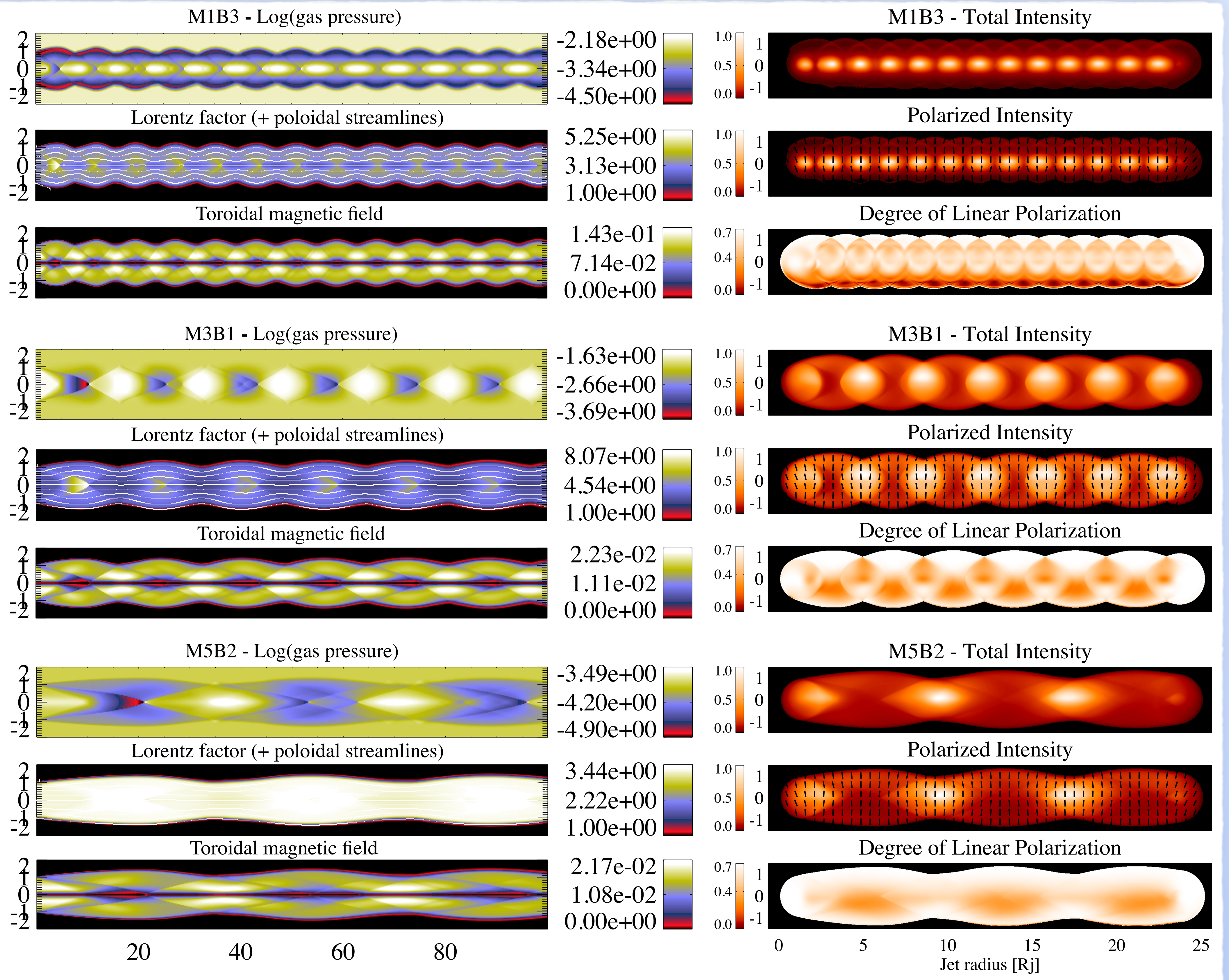


Fig 2. Left panel: gas pressure, Lorentz factor, and toroidal component of the magnetic field for each representative model. **Right panel:** total and linearly polarized intensity, with Electric Vectors Position Angle (EVPAs) overplotted as black bars, and degree of linear polarization of the same jet models. The viewing angle is 10°.

Asymmetry and Spine Brightening

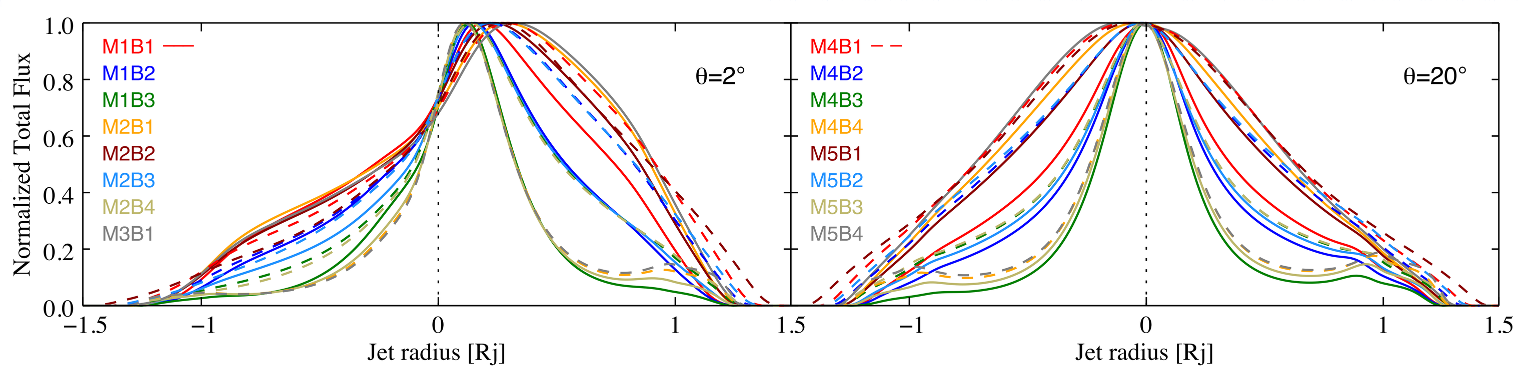


Fig 3. Normalized total flux transverse profiles for the whole set of models and two different viewing angles: 2° and 20°.

- The helical magnetic field produces an emission asymmetry between the top and bottom halves of the jet (compare both panels of Fig. 3).
- Jet models with large magnetizations present spine brightening (e.g. M1B3).

Polarization Signatures

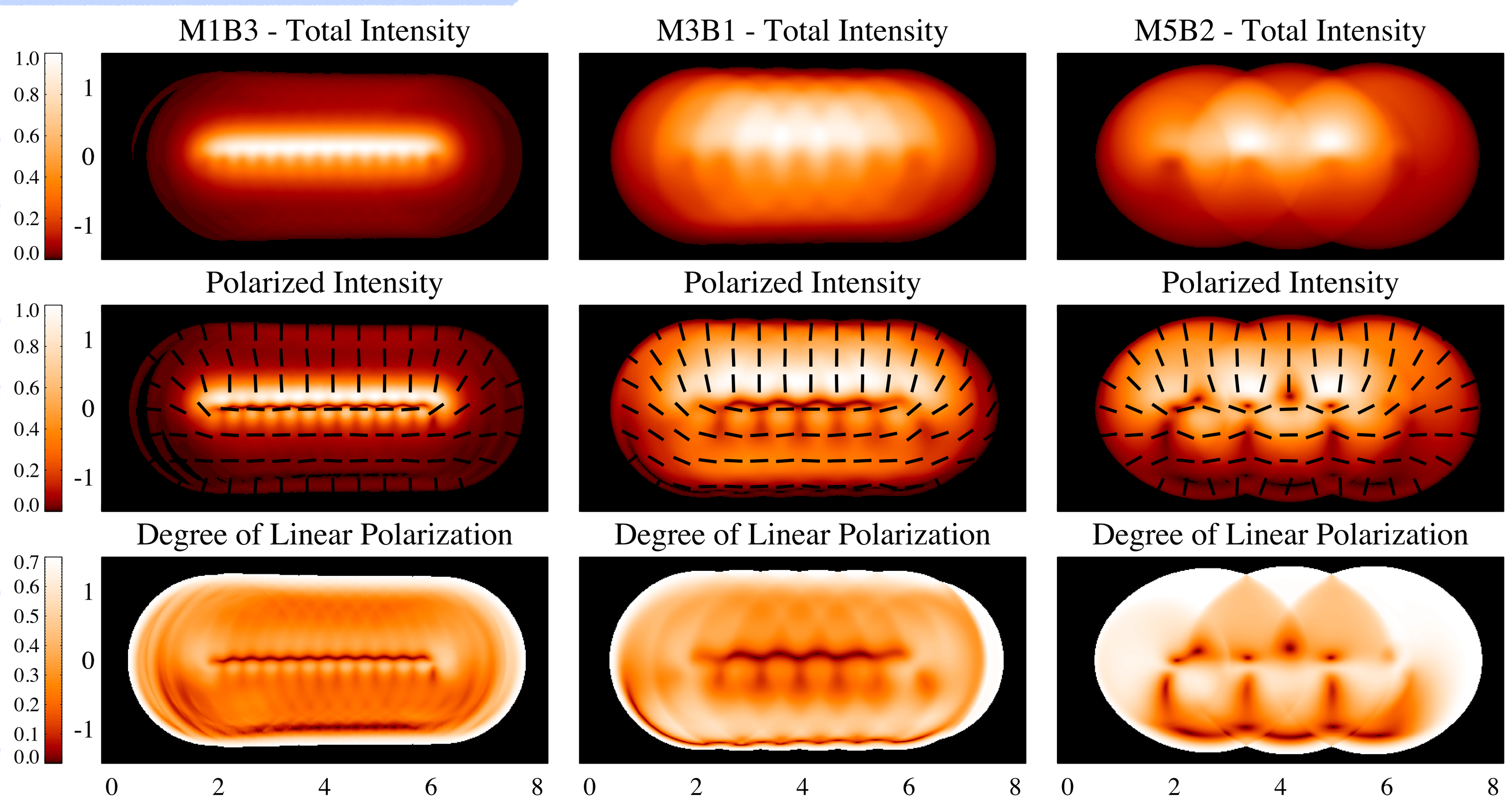


Fig 4. Same as the right panel of Fig. 2, but for a viewing angle of 2°.

- The EVPAs show a bimodal distribution at small viewing angles being either perpendicular or aligned with the jet axis (see Fig. 4), expected for a helical magnetic field (Lyutikov+ 2005, MNRAS, 360, 869). For larger angles, the EVPAs remain perpendicular (see Fig. 2).
- Small variations in the polarization angle of up to 26° are observed around stationary knots (e.g. M5B2, Fig. 4), caused by a break in the Stokes U symmetry, and induced by the presence of several RCs. Can be used as a tracer for identifying RCs in VLBI observations.
- The fully uniform helical magnetic field produces asymmetry, stratification, and the maximum value of the polarization degree.

Particle Injection

- The particle injection method plays an important role determining the emission of highly magnetized jets.
- When considering a non-thermal energy based on the magnetic energy instead of the thermal internal energy, the spine brightening seen in the magnetic model M1B3 disappear (compare Fig. 5 with Fig. 2).

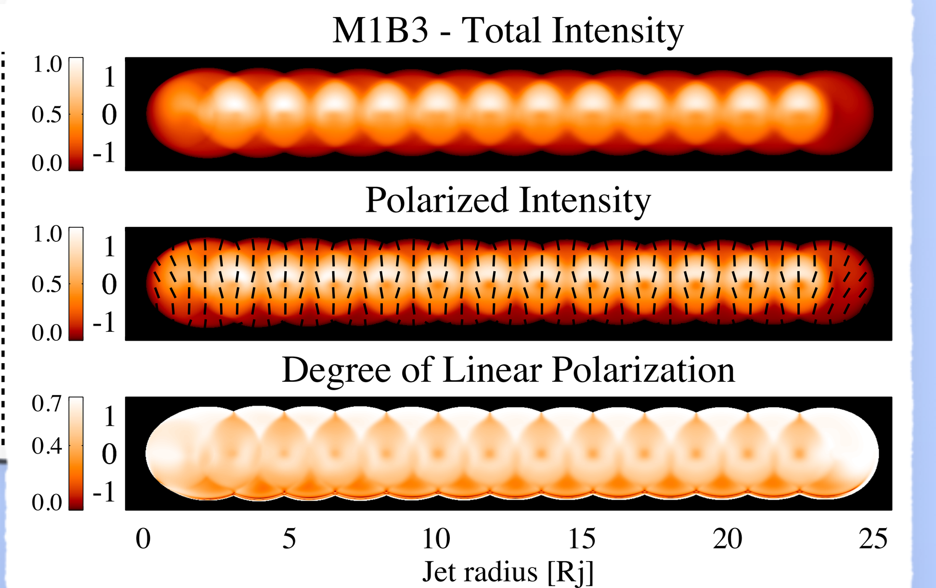


Fig 5. Magnetically dominated model M1B3 computed following a power-law energy distribution determined by the magnetic energy density instead of the internal energy density.

Fuentes et al. 2018, ApJ, 860, 121
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