Simulations of the parsec-scale relativistic jet in 3C 273

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Outline

• Introduction.
• Linear analysis.
• Numerical simulation.
• Discussion and conclusions.
Introduction (from kpc to pc scale)

• Kpc scale jet:
  – Observed up to 60 kpc.
  – No counter jet (relativistic beaming or asymmetry?).
  – Observed from radio to X-rays.

• pc scale jet:
    • \(\sim 15^\circ\) to the line of sight.
    • \(\gamma \sim 5-10\).
  – Jet/counter-jet flux asymmetry: \(\gamma > 3\).
  – Periodicities in emission (Abraham & Romero 1999, Qian et al 2001):
    • \(\sim 15\) yrs (precession).
    • \(\sim 1\) yr (superluminal component ejection).
    • Ejection velocity decreasing.
  – Higher frequencies show more compact jet (stratification).  Bonn 10-1-2004
Introduction (pc scale jet)

- VSOP observations:
  - 240 emission profiles. 2 - 3 components.
  - Central (strong) component seems to move ballistically.
  - Fitted profiles to double gaussians.
  - Obtained characteristic wavelengths (double helix) and interpreted them as modes of KH instability.
  - Fitted physical parameters using linear stability theory approximations (Hardee 2000).

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Linear analysis

λ(Hs) λ(Es) λ(Hb1,Eb1) λ(Hb3,Eb2) γ Mj,rel η Rj
Amp  Amp  Amp  Amp  γ Mj,rel η Rj (mas) (mas) (mas) (mas) (pc)

18 12 4
1.5 2.2 0.25

• Powerful tool to derive jet parameters from observables!!!
• γ≈2.1 < 5-10 for superluminal components: Analysis applies to underlying flow.
• Is linear regime able to explain observable structures?
  - Numerical simulations reproduce linear regime (Perucho et al. 2004a) and transition to non-linearity (Perucho et al. 2004b).
Numerical simulation (i)

- 3D RHD cylindrical jet
  - Start with a stationary jet with the given parameters.
  - Axial size corresponds to the observed region in LZ01.
  - Jet is perturbed at the inlet with appropriate frequencies.
  - 16 cells/R_j transversal, 4 cells/R_j axial.
  - Injection and outflow boundary conditions.
  - Thick shear layer between jet and external medium.
  - 8 processors in SGI Altix CERCA during ~1 month.
Numerical simulation (ii)

Model = 3C273
Time = 2.50000 yrs

LORENTZ FACTOR
Axial cut x=0, (mas)

Axial cut y=0, (mas)

z=2/3 L

z=L

Model = 3C273
Time = 2.50000 yrs
Pressure perturbation $V_z=0.6$ profile

z=3 mas

z=6 mas

z=9 mas

z=12 mas

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Numerical simulation (iii)

Relative fourier mode amplitudes

Time = 80.0864
Numerical simulation (iv)

Relative Fourier mode amplitudes

Time = 545.126
Numerical simulation (v)

Relative fourier mode amplitudes

Time = 1097.06
Discussion (i)

- From observations and linear analysis, we can obtain parameters for numerical simulations.

- Numerical simulation: The jet is disrupted and the Lorentz factor drops.
  - Drop in emission after VLBI jet could be due to:
    - Disruption of underlying flow.
  - In this case superluminal components could play a central role in keeping collimation up to the kpc scale jet, where strong interaction with external medium plus reacceleration would rise emission again.
Discussion (ii)

- Adiabatic expansion (the jet keeps fast but we don’t see it). Possible reasons for differences:
  - Linear theory approximations may not be accurate.
    » Factor 1.5-2 difference in derived wavelengths with solver and approximations in Hardee (2000): π phase could explain factor 2.
  - Magnetic fields may play an important role (Asada et al. 2002).
  - KH theory and our simulation apply to underlying flow alone.
  - Superluminal components should be included:
    » Include also periodicities? New simulations…(Abraham & Romero 1999, Qian et al. 2001)
  - Arbitrary initial amplitudes.
  - Errors from numerical methods (lack of resolution).
Discussion (iii)

• Possible stabilizing factors:
  – Superluminal components.
  – Thicker shear layer.
  – Decreasing density atmosphere.
  – Stabilizing configuration of magnetic field (RMHD simulations?).
Discussion (iv)

- Mode wavelengths found via Fourier analysis:
  - Close to observed for longer wavelengths: they dominate by the end of the simulation.
  - Shorter modes disappear from the simulation. Maybe their amplitude is increased in the real jet by growing perturbations (superluminal components may excite them as trailing components, Agudo et al. 2001).

- This work represents our first step in trying to understand relativistic jet physics through stability analysis in combination with 3D relativistic hydrodynamical simulations.