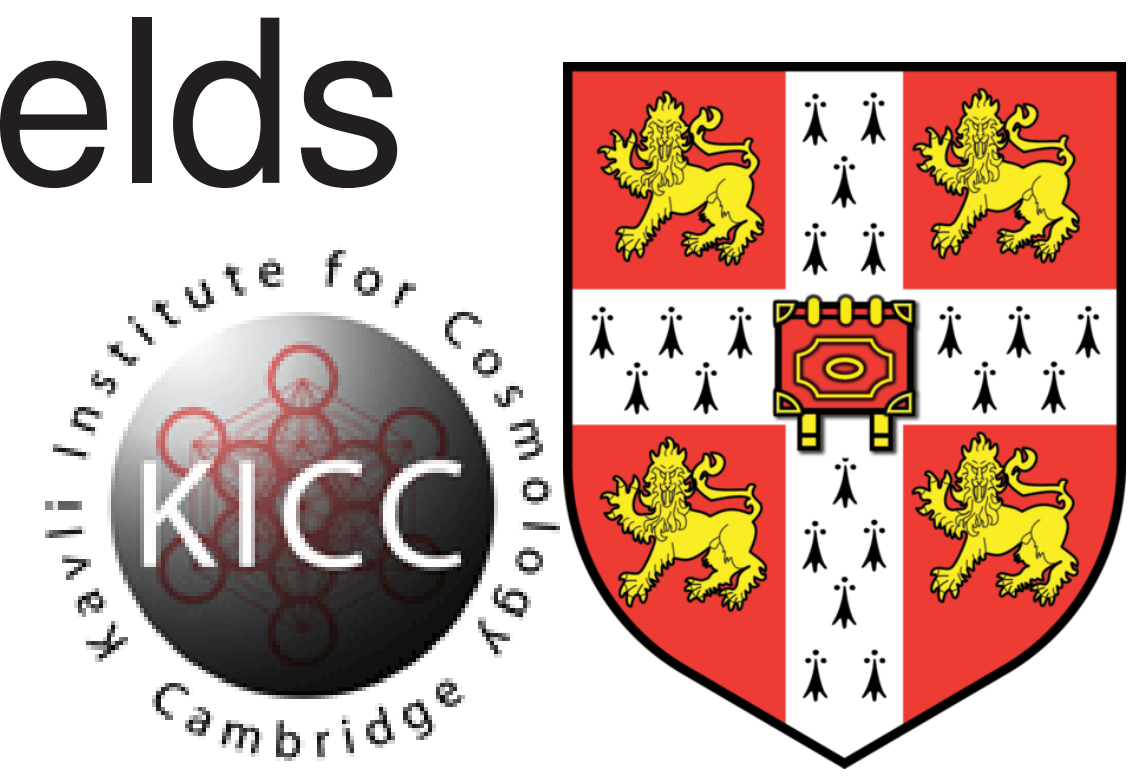


3DMHD simulations of the evolution of magnetic fields in Fanaroff-Riley class II radio sources

Martín Huarte Espinosa[†], Martin Krause and Paul Alexander.

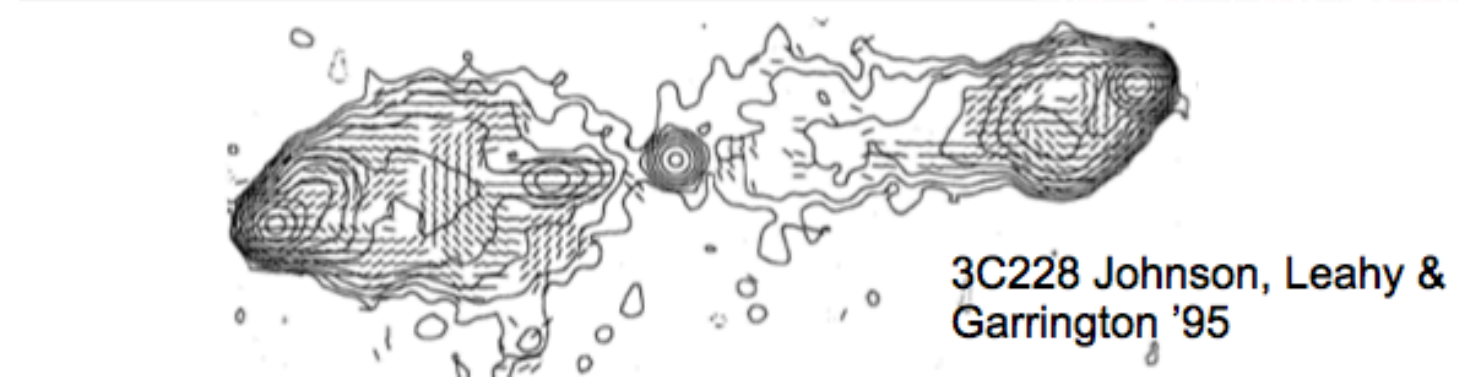
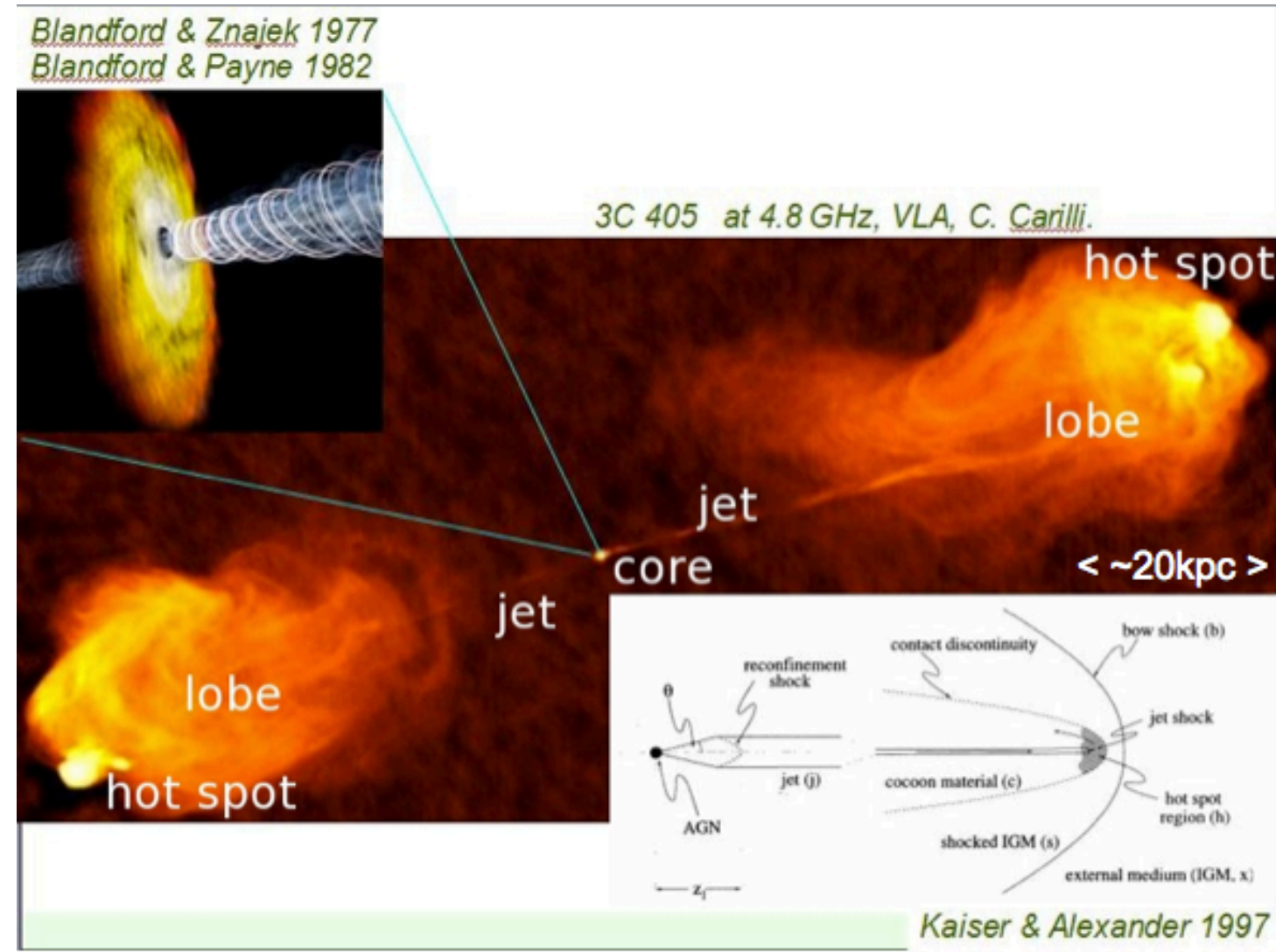
[†]Department of Physics and Astronomy, University of Rochester, 600 Wilson Boulevard, Rochester, NY, 14627-0171; Kavli Institute for Cosmology Cambridge, Madingley Road, Cambridge CB3 0HA, UK ; <martinhe@pas.rochester.edu>



Introduction

FRII radio sources¹ are extragalactic, synchrotron in nature and usually show linear polarization fractions within² 10–50% (see Fig. →). Stokes parameters are used to infer the magnetic structure in FRIIs. Observed magnetic polarization vectors are²:

- parallel to jets and to lobe boundaries
 - follow flux intensity gradients perpendicularly
 - follow a line between multiple lobe hot spots.
- The linear polarization fraction is typically higher at²:
- jet edges than in jet beams
 - source edge than in its cocoon.



Open questions: What is the magnetic structure in FRIIs?. How does it evolve?. Does it correlate with jet properties?

Results: Synthetic polarimetry

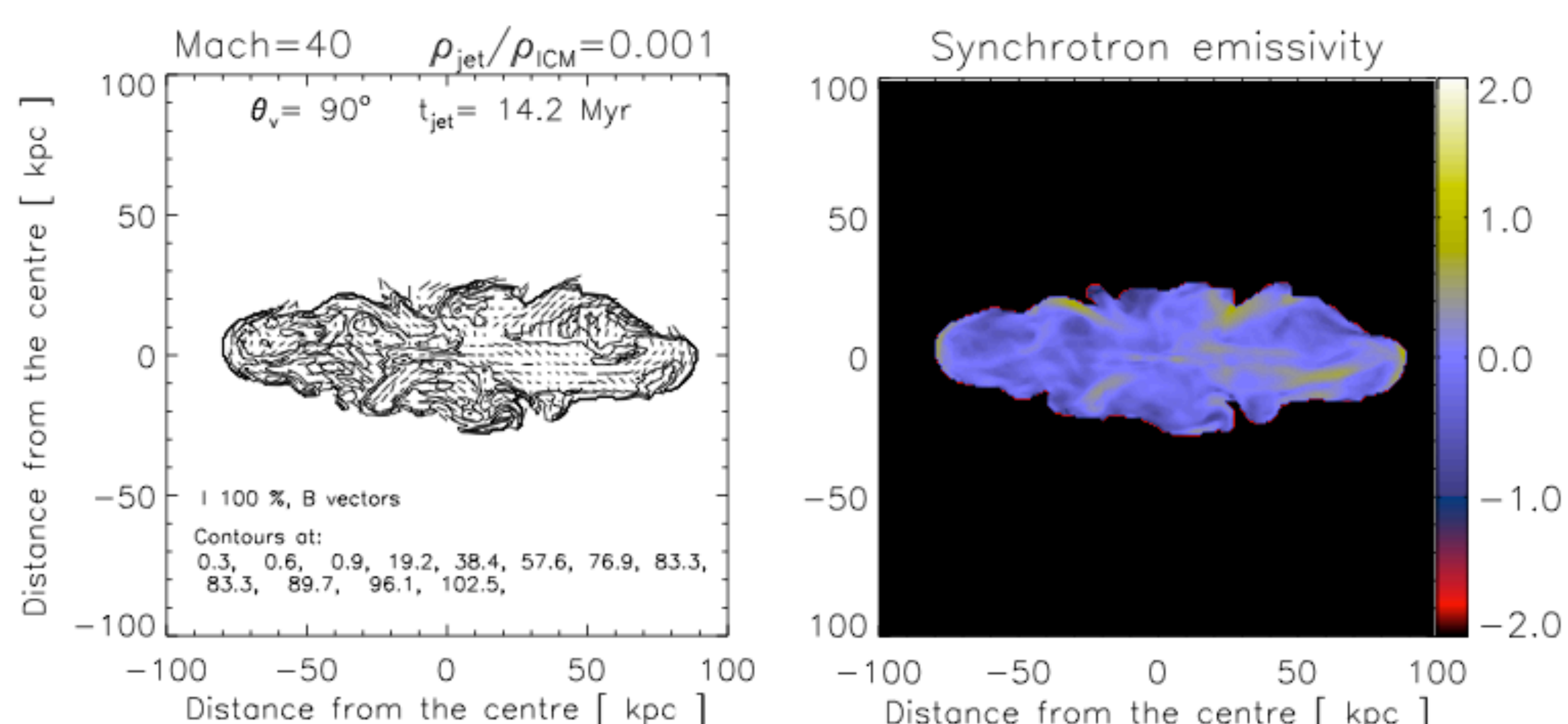
Using the simulated data we integrate the synchrotron emissivity $J(\mathbf{x}_\perp, \nu, t) \propto \frac{1}{l} \int_0^l \tau(\mathbf{x}, t) \delta_\tau p_j(\mathbf{x}, t) \nu^{-0.7} [B'_x(\mathbf{x}, t) + B'_y(\mathbf{x}, t)]^{(1.7)/2} dZ_\parallel(t)$, and the Stokes parameters

$$I(\mathbf{x}_\perp, t) = \frac{1}{l} \int_0^l \delta_\tau [B'_x(\mathbf{x}, t)^2 + B'_y(\mathbf{x}, t)^2] dZ_\parallel(t),$$

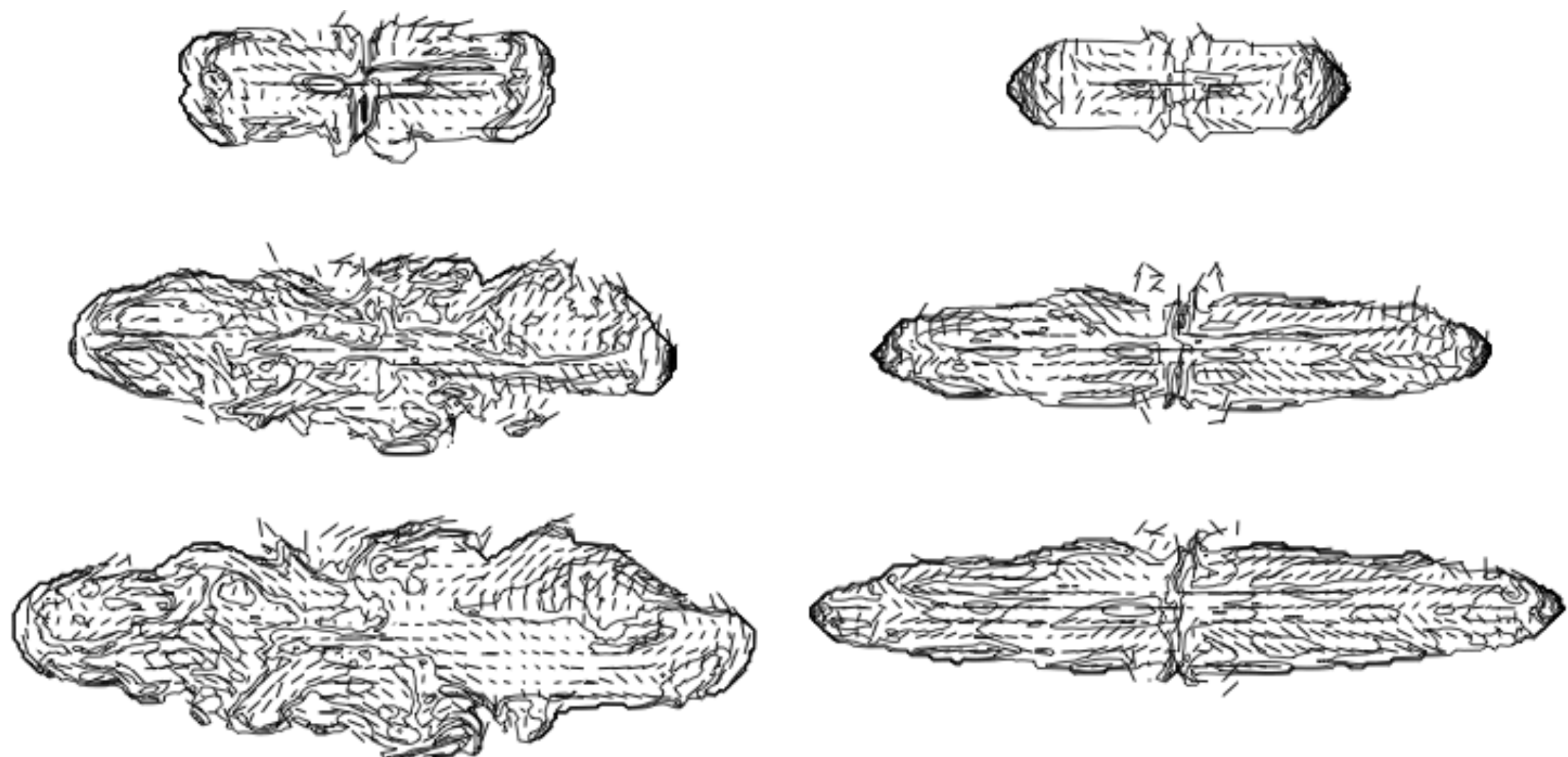
$$Q(\mathbf{x}_\perp, t) = \frac{1}{l} \int_0^l \delta_\tau [B'_x(\mathbf{x}, t)^2 - B'_y(\mathbf{x}, t)^2] dZ_\parallel(t),$$

$$U(\mathbf{x}_\perp, t) = \frac{1}{l} \int_0^l \delta_\tau 2 B'_x(\mathbf{x}, t) B'_y(\mathbf{x}, t) dZ_\parallel(t),$$

through the source, along the line of sight dZ_\parallel . Above, l is the line of sight length, τ is a jet tracer field, p_j is the jet pressure, $\nu = 8 \text{ GHz}$ is the radiation frequency, B'_x and B'_y are the magnetic field components perpendicular to dZ_\parallel , and $\delta_\tau = 1$ ($=0$) inside (outside) the cocoon. The **polarization angle** and the **degree of linear polarization** are given by $\chi = \frac{1}{2} \tan^{-1}(U/Q)$, $d_p = \sqrt{U^2 + Q^2}/I$. Synthetic polarization maps are produced at different simulation times, t_{jet} , and at different viewing angles, θ_v .



Left: polarization map. Lines follow χ_B and their length is proportional to $d_p/\langle I \rangle$, where $\langle I \rangle$ is the mean intensity value. Vectors are superimposed on linear $J/\langle J \rangle$ contours. **Right:** $J/\langle J \rangle$ map in logarithmic scale. The initially random magnetic fields have been ordered by the magnetohydrodynamic processes.



Synthetic polarization evolution at $\theta_v = 90^\circ$. **Left:** $\eta = 0.001$; Mach=40; $t_{\text{jet}} = \{4.7, 9.5, 14.2\}$ Myr, top to bottom. **Right:** $\eta = 0.01$; Mach=80; $t_{\text{jet}} = \{1.8, 3.6, 4.4\}$ Myr, idem.

References

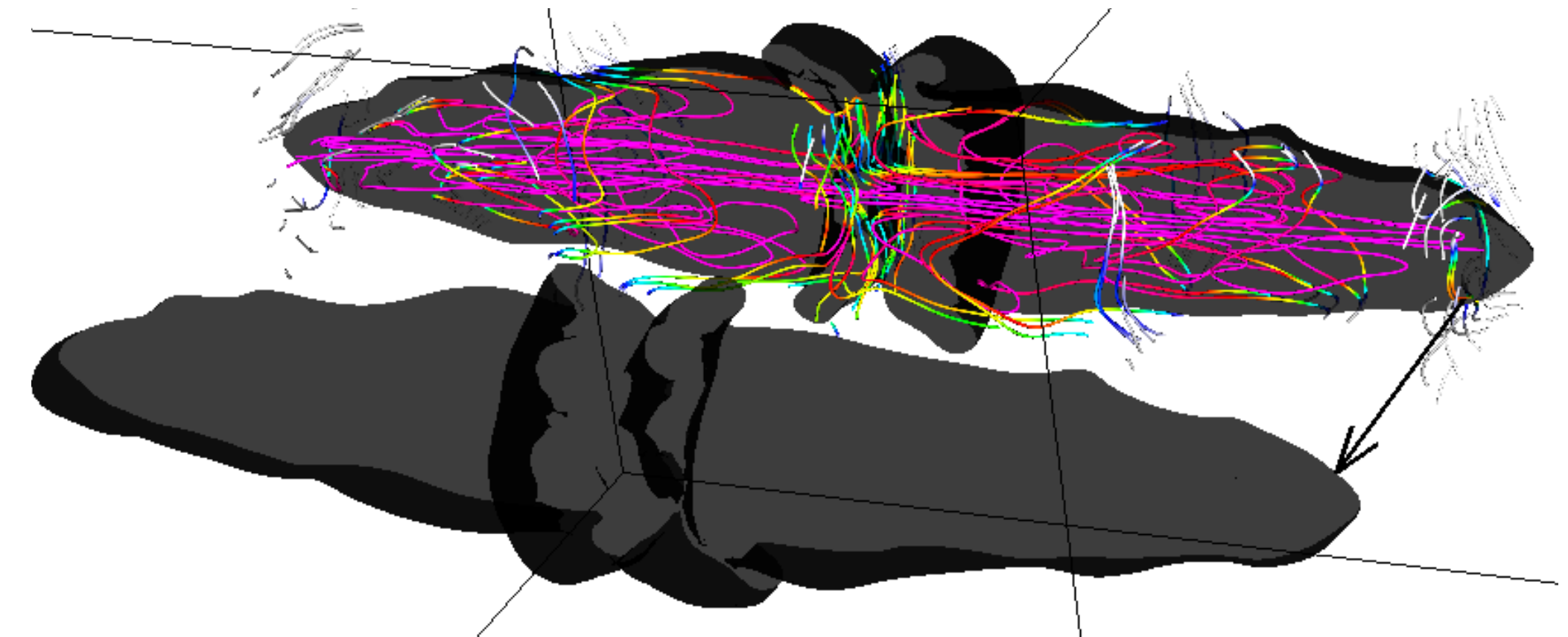
[1] Fanaroff B. L. & Riley J. M., 1974, MNRAS, 167, 31; [2] Bridle A. H. & Perley R. A., 1984, ARA&A, 22, 319; Saikia, D. J., & Salter, C. J., 1988, ARAA, 26, 93; [3] Fryxell B. et al., 2000, ApJS, 131, 273; [5] Mullin, L. M., Hardcastle, M. J. & Riley, J. M., 2006, MNRAS, 372, 113 (and references therein); [6] Matthews, A.P. & Scheuer, P.A.G. 1990, MNRAS 242, 616.

The Model

Using Flash 3.1³ we solve the equations of 3DMHD. Cubic Cartesian domain with 200^3 cells. Initial ambient implemented as:

- monoatomic ideal gas ($\gamma = 5/3$)
- $\rho_{\text{amb}} = \frac{\rho_0}{1 + (r/a_0)^2}$
- Magnetohydrostatic equilibrium with central gravity
- Magnetic Kolmogorov turbulence

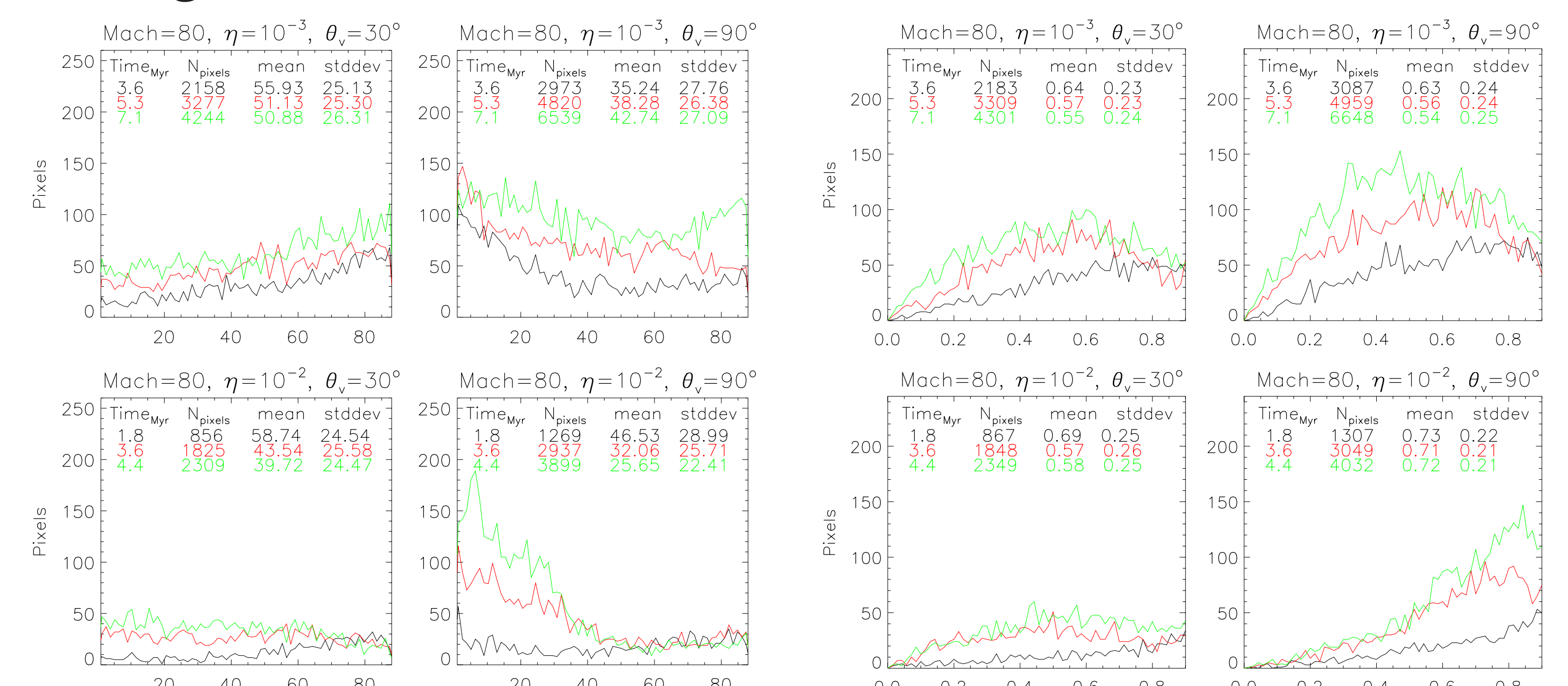
lent structure with $\beta_{\text{magnetic}} \gtrsim 10$. Mass and x -momentum are injected in a central cylinder which takes weak and random magnetic fields (similar as in [6]). We investigate with jet velocities of $\{40, 80, 130\}$ Mach as well as $\eta = \rho_{\text{jet}}/\rho_{\text{amb}} = \{10^{-2}, 10^{-3}\}$.



Magnetic field lines of the source with $\eta = 0.01$ and Mach=80 at 4.4 Myr. Field line colors follow the jet tracer field: jet lines are purple; cocoon lines are red, blue, yellow and green; ambient lines are white. Cocoon density contrast surface shown in black. The cavity expands hypersonically as it is filled with light gas and magnetic fields from the jets.

Analysis

Histograms

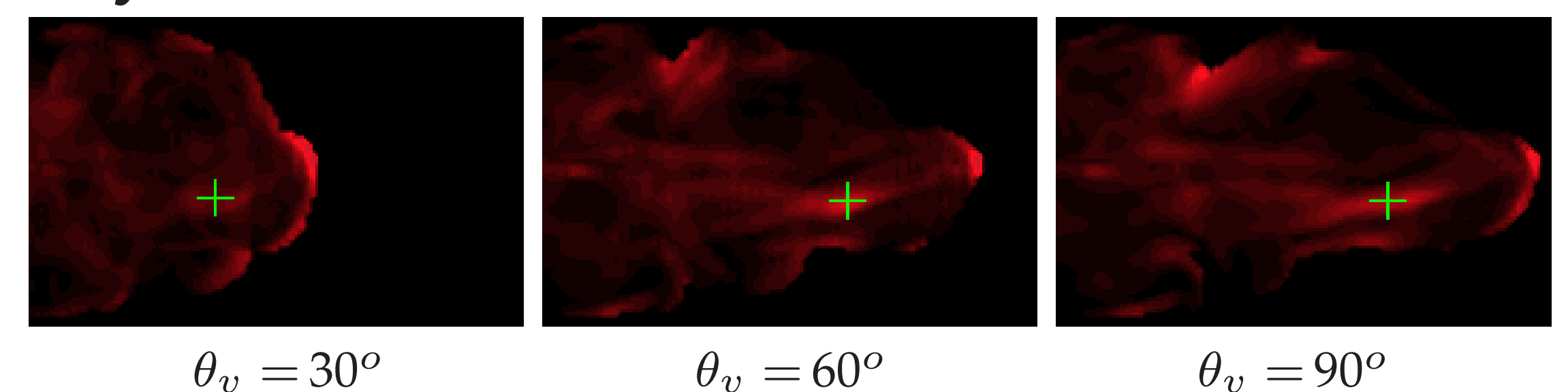


Polarization angle [deg]

Linear polarization fraction

In the heavier sources seen close to the plane of the sky (bottom right), only, we find magnetic vectors predominantly aligned with the jet axis, as observed. Lighter sources (top row) show around 55% polarization independent of viewing angle towards the end of the simulation. This agrees reasonably well with observations, in contrast to the heavier jets, for which the polarization is too high.

Emissivity filaments



Right lobe of the source with $\eta = 0.001$ and Mach=40 at $t_{\text{jet}} = 14.2$ Myr. Green “+” symbol gets shorter and dimmer as θ_v decreases. This suggests a tube-like filament.

Conclusions

- Jets injected with initially random fields develop ordered fields by magnetohydrodynamic processes within the radio source
- Filaments suggest that turbulence develops in evolved sources
- Polarimetry statistics correlates with time, θ_v and η but not so with \vec{v}_{jet}
- Linear polarization fraction decreases as sources expand
- Lighter jets show $d_p \sim 55\%$ at the end of the simulation independently of θ_v . This agrees better with observations than for the heavier sources.
- The heavier sources show better, and more realistic, field alignment with the jet axis than the Lighter ones.
- Some initial order is possibly required in order to meet all the constraints simultaneously.

Acknowledgements

The software used in these investigations was in part developed by the DOE-supported ASC / Alliance Center for Astrophysical Thermonuclear Flashes at the University of Chicago. MHE acknowledges: funding from The National Council of Science and Technology of Mexico 196898/217314; Dongwook Lee for the 3D-USM-MHD solver of Flash 3.1.