Modeling AGN Jets as Expanding Spheromak with Helicity Injection

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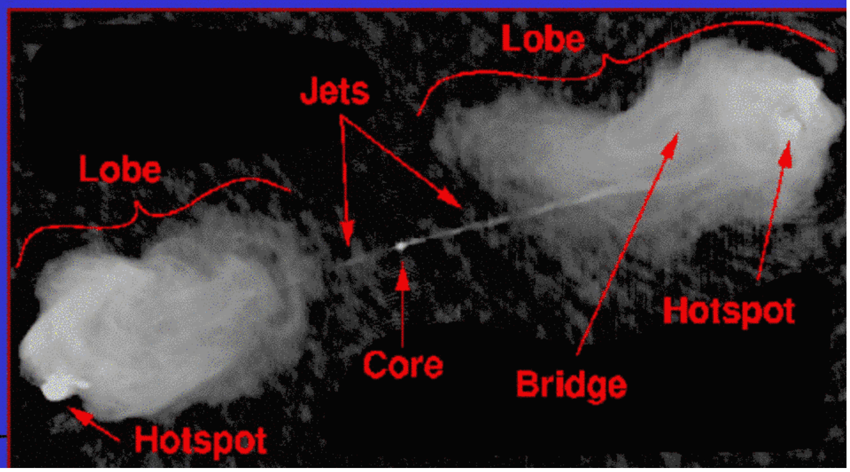
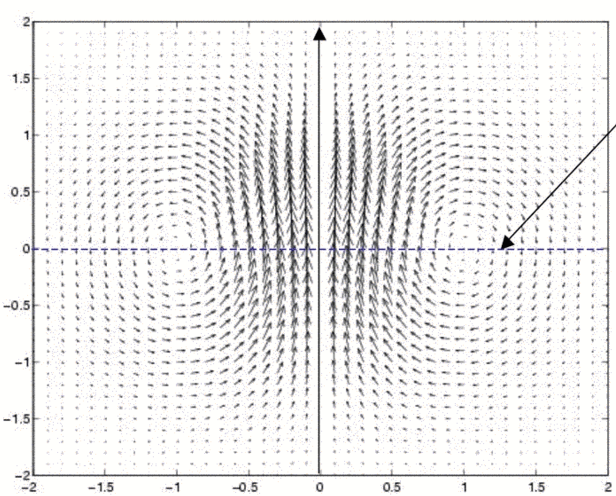
- Engine; Injection;
- Collimation; Propagation; Stability;
- Lobe Formation;
- Dissipation;
- Magnetization of IGM



NNSA

Key Ingredients: I

Initial magnetic fields are localized to the disk and Self-supported by internal currents.



(imaginary) disk

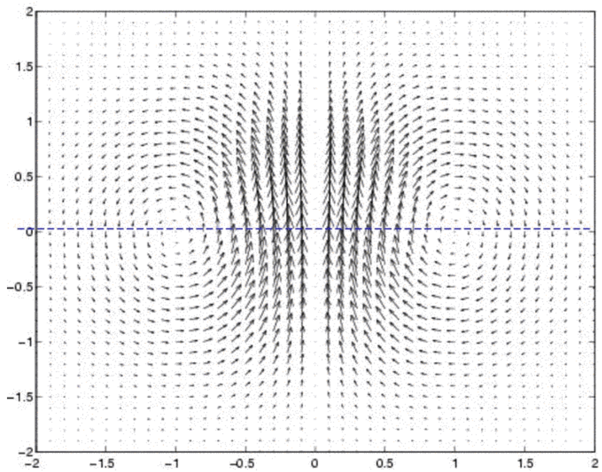
Flux fn. (cylin.) $\Psi = r^2 \exp(-r^2 - k^2 z^2)$

$$B = \begin{cases} B_r = 2k^2 z\, r \exp(-r^2 - k^2 z^2) \\ B_z = 2(1 - r^2) \exp(-r^2 - k^2 z^2) \end{cases}$$

Key Ingredients: I

Calculating Ψ

- Disk: $r_{min} = 3e13$ cm, $r_{max} = 3e18$ cm
- B: 10^4 Gauss at r_{min}, $B \propto r^{-5/4}$
- Ω: 7e-4 (rad/s) at r_{min}, $\Omega \propto r^{-3/2}$

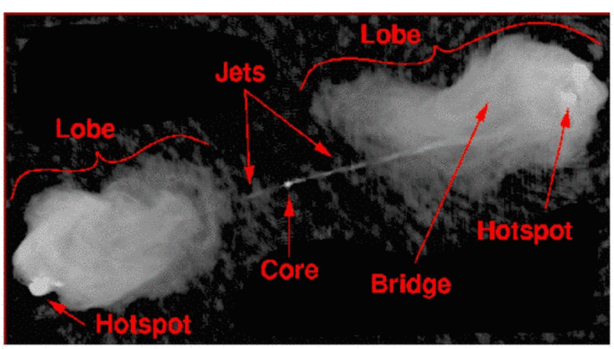


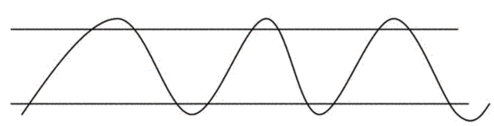
Then

$\Psi = 4 \times 10^{35}\ B_4\ R_{pc}^{3/4}$ (G cm^2)

Key Ingredients: II

Injected toroidal flux F_ϕ >> Poloidal flux Ψ





- $B_\phi = B_{\phi 0} (Z_{max}/z)$
- $R \sim 0.01$ L
- $L \sim 10^{24}$ cm
- $B_{\phi 0}$: μG at Z_{max}

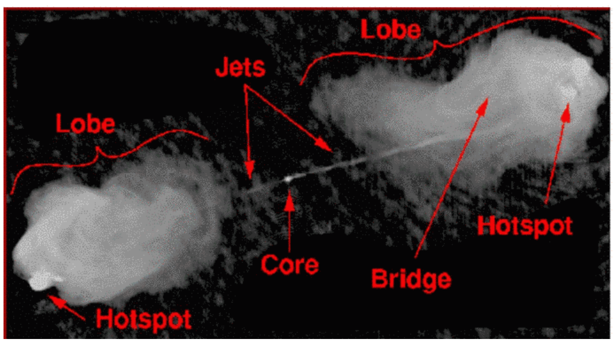
$F_\phi = 3 \times 10^{41}$ (Gcm^2)

Injected Helicity

$$K_{inj} = 4\pi \int_{\Psi_{min}}^{\Psi_{max}} d\Psi \cdot \Psi \cdot \Delta\Omega(\Psi) \approx 10^{77} (G^2 cm^4)$$

for 10^7 yrs and a Keplerian disk.

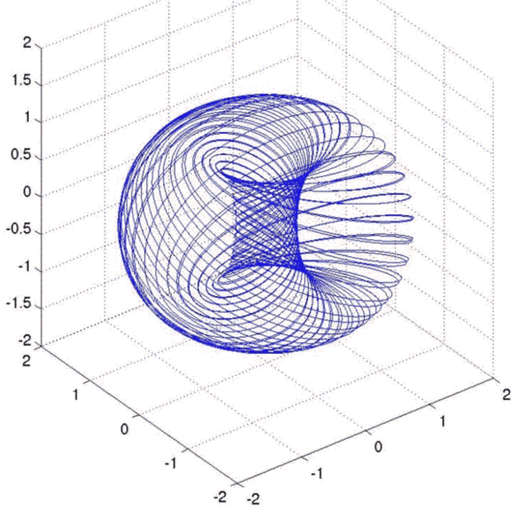
Simple estimate: $K = \Psi F_\phi = 10^{77}$ (G^2cm^4)



Key Ingredients: III

Injection rate vs "communication" speed

- **Impulsive Injection:**
  Evolution of a highly wound and compressed magnetic "spring"



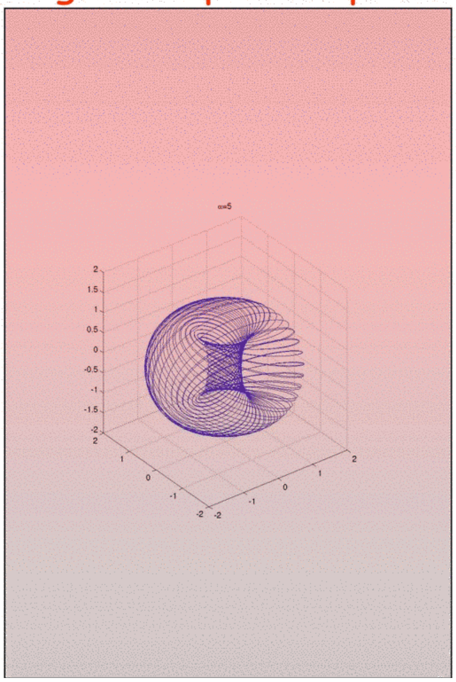
- **Continuous Injection:**
  Evolution of "magnetic tower" with continuous injected toroidal
- Initial: a magnetic spring (α=3).
- Toroidal field added over a small central region:

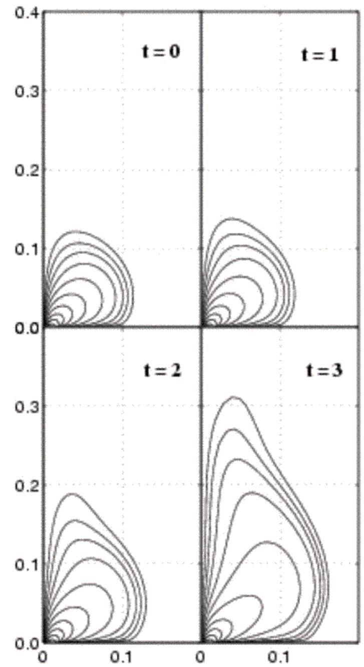
$$\frac{\partial B}{\partial t} = B(r,z)\ \gamma(t)$$

- Adding twists, self-consistently collimate and expand.

Key Ingredients: IV

Injected magnetic structure is confined by background plasma pressure (could be very small)





Li et al. (2001)

Collimation; Propagation

Run A: impulsive injection, α=50

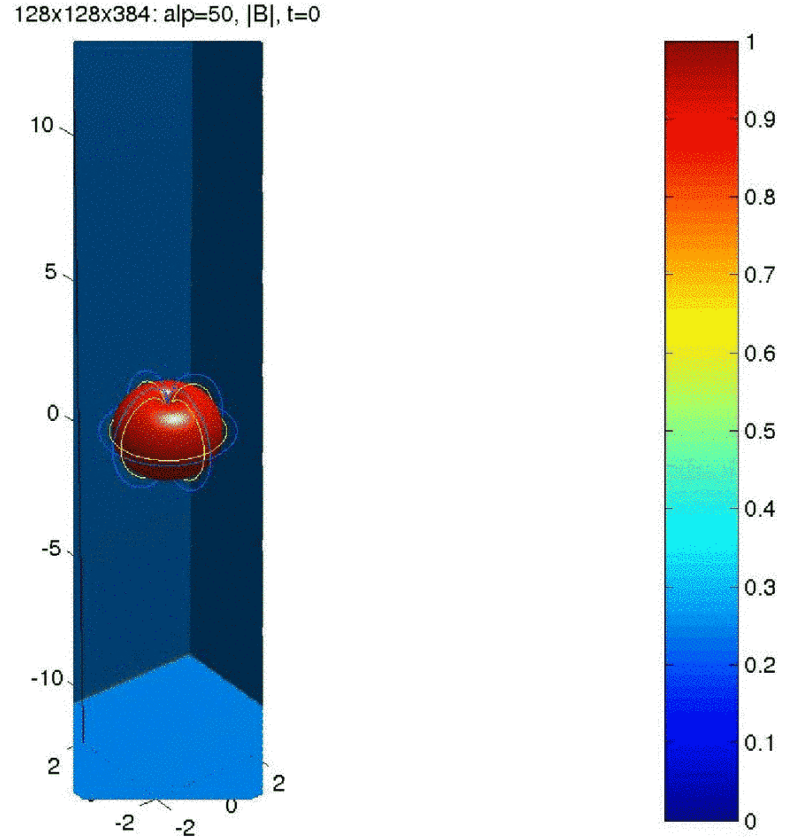
$v_{inj} >> v_A > c_s$

Run B: continuous injection, α=3, γ=3

$v_A > c_s$, scanning through γ (v_{inj})

Run A

Total |B|

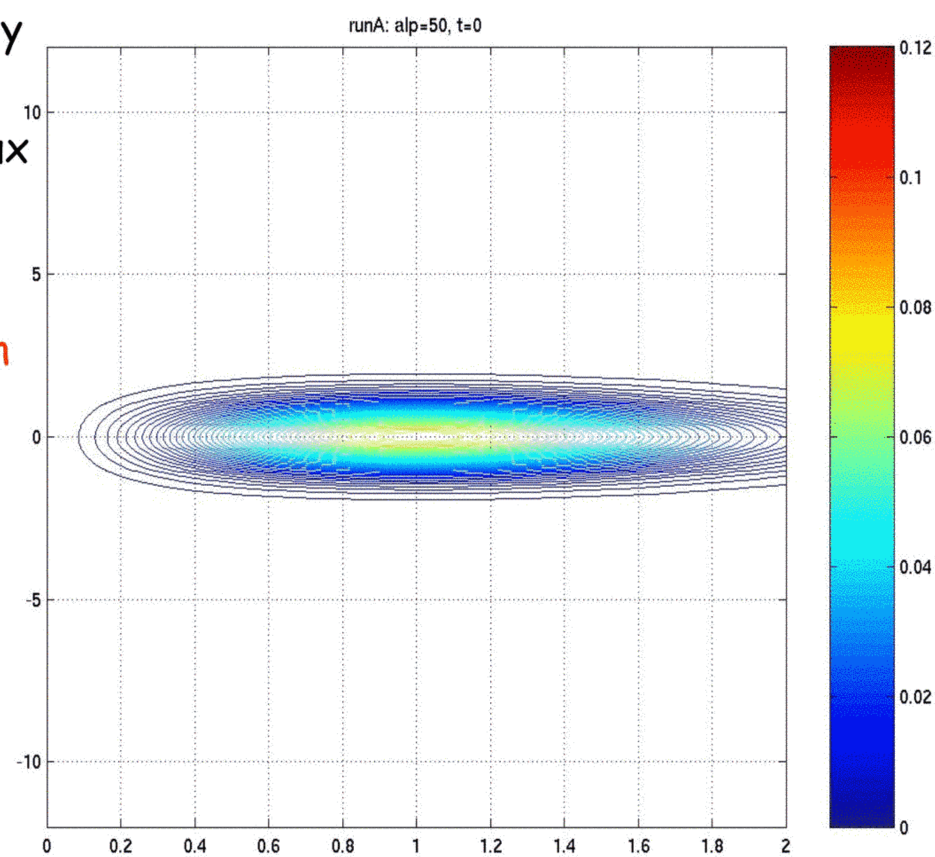


Azimuthally averaged Poloidal Flux (n=0)

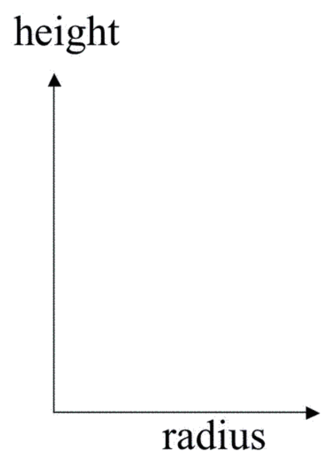
3D Flux Conversion

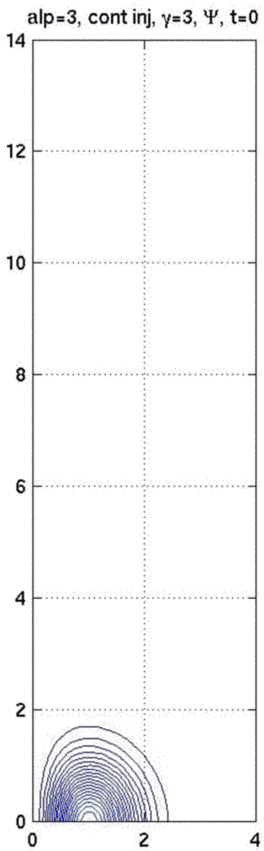
height

radius

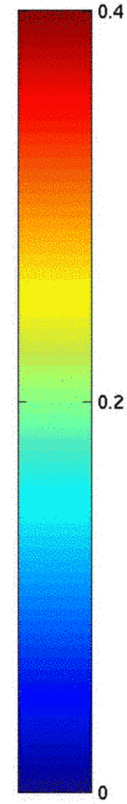


RunB: Continuous Injection



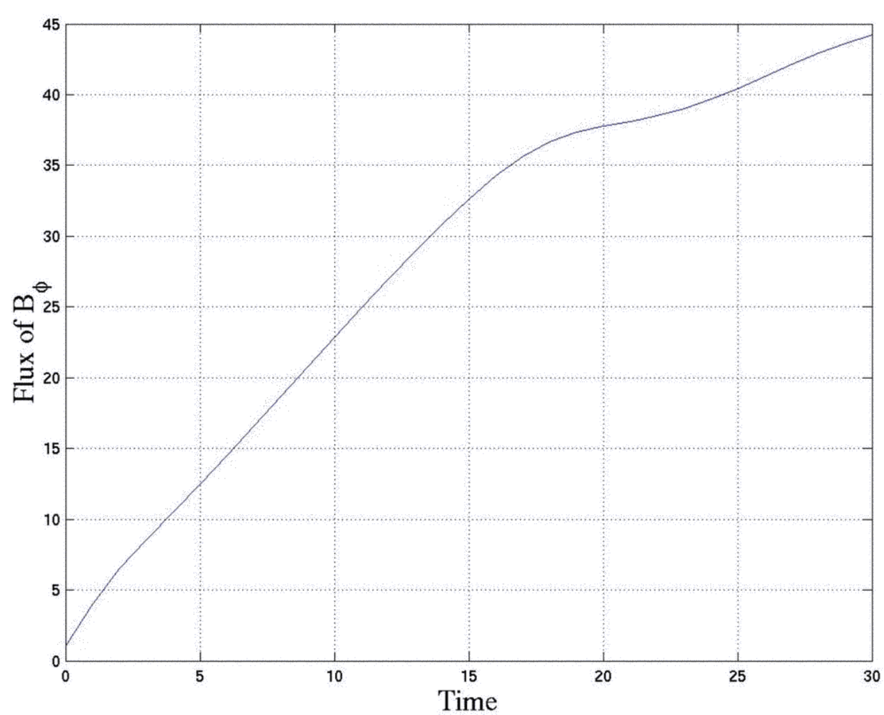


Azimuthally Averaged Poloidal Flux



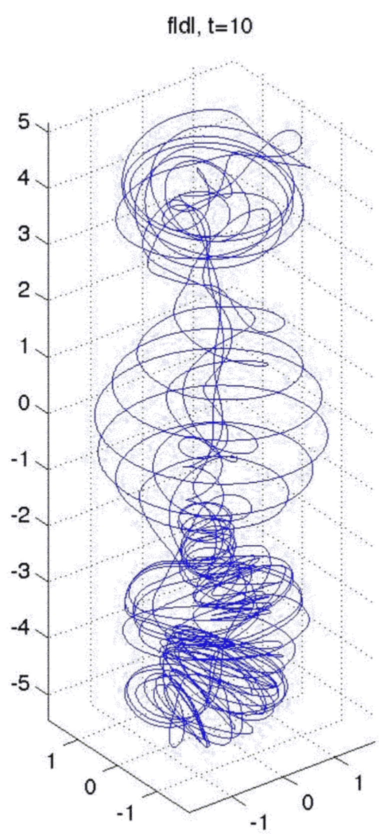
Run B: Continuous Injection

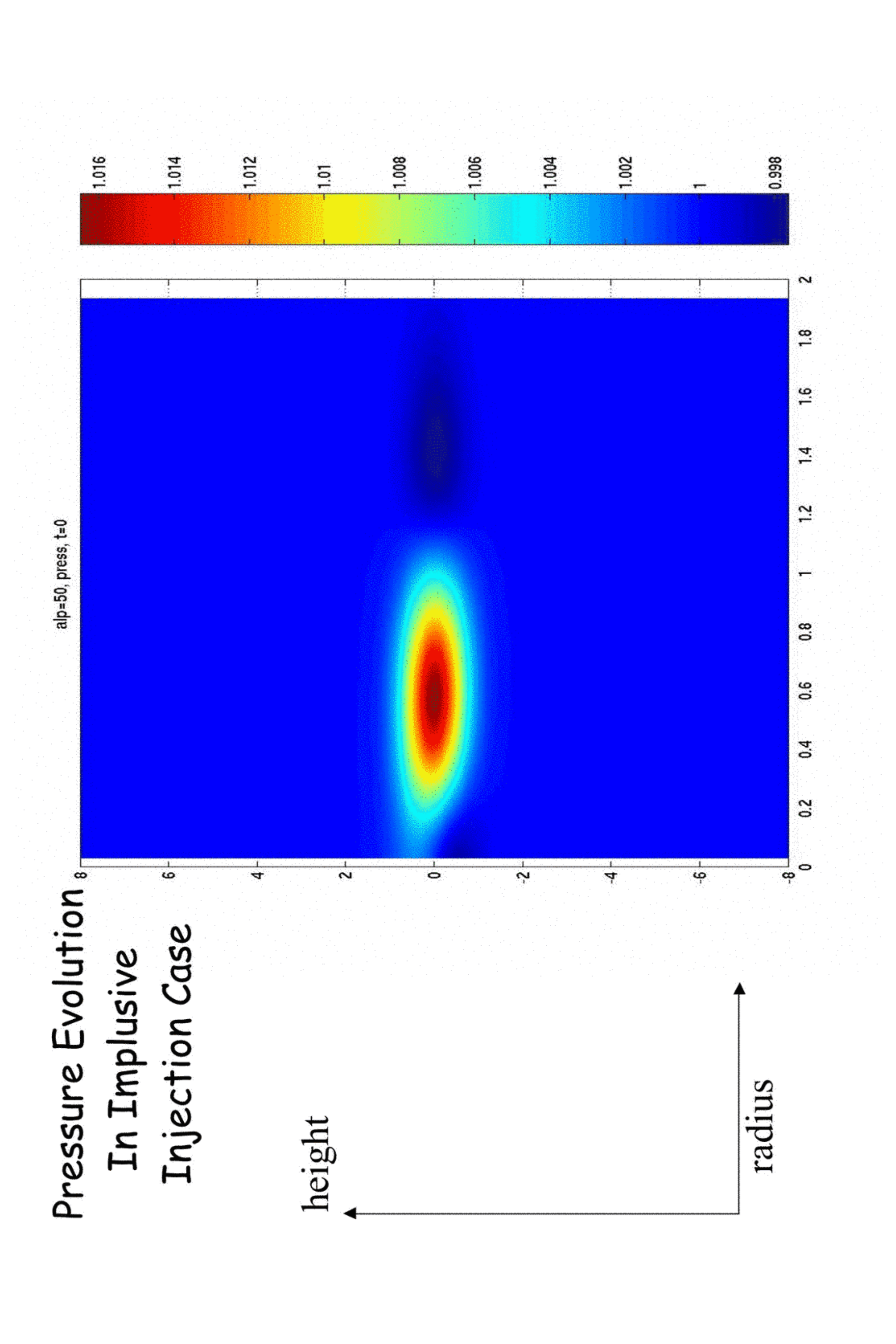
Injected toroidal flux vs time

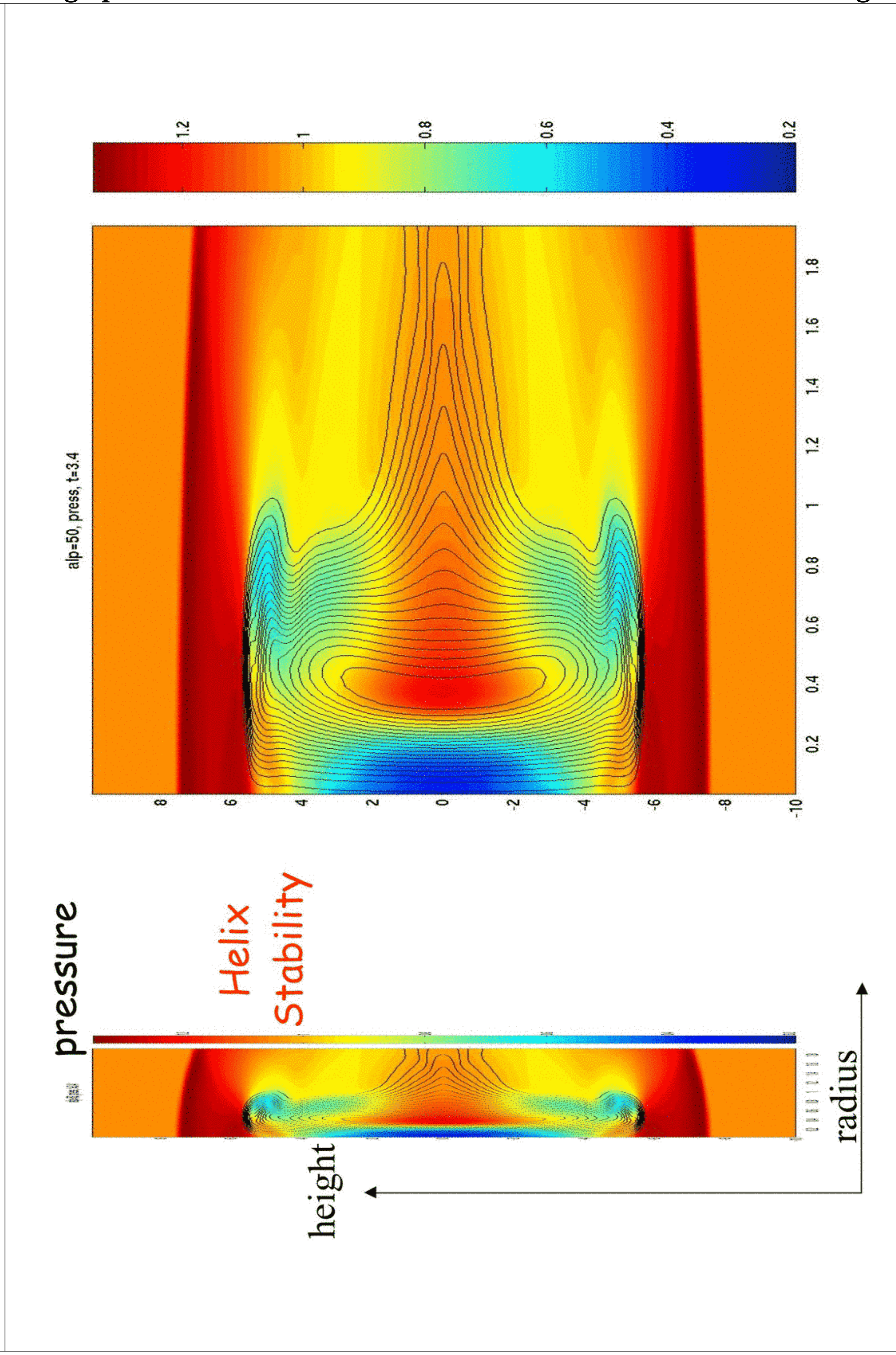


Stability and Lobe Formation

- Dynamic: moving, q-profile changing
- 3D Kink unstable in part of helix: twist accumulation due to inertial/pressure confinement
- Pressure profile: hollow
- Velocity profile ?




Pressure Evolution
In Implusive
Injection Case
alp=50, press, t=0
height
radius


alp=50, press, t=3.4
pressure
Helix
Stability
height
radius

Conclusion

- Simple estimates of poloidal flux in the disk and toroidal flux in the jet/lobe seem to be consistent with total helicity injected through the disk, 10^{77} G^2cm^4.
- Implication, though, is that lobes are NOT relaxed, i.e., energy x size = 10^{85} G^2cm^4 >> helicity.
- Fast injection leads to better collimation and stability.
- 3D kink instability occurs first at the "head" of the helix, suggestive for lobe formation.