CENTAURUS A

NUMERICAL STUDY OF NON-THERMAL EMISSION FROM LAGRANGIAN PARTICLES IN AGN ENVIRONMENTS.

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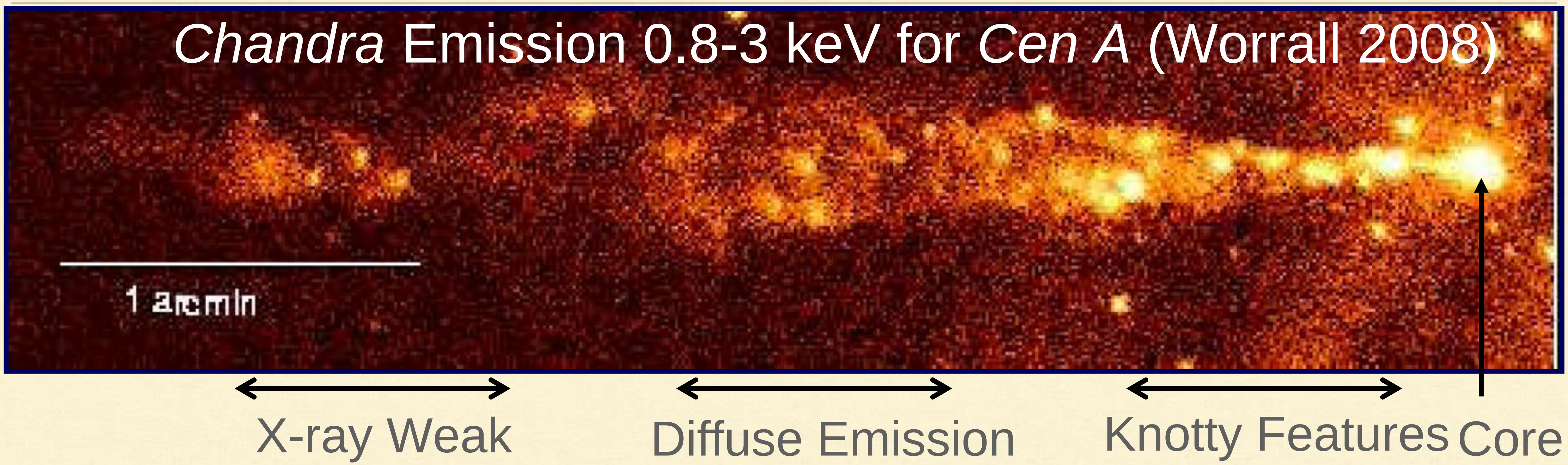
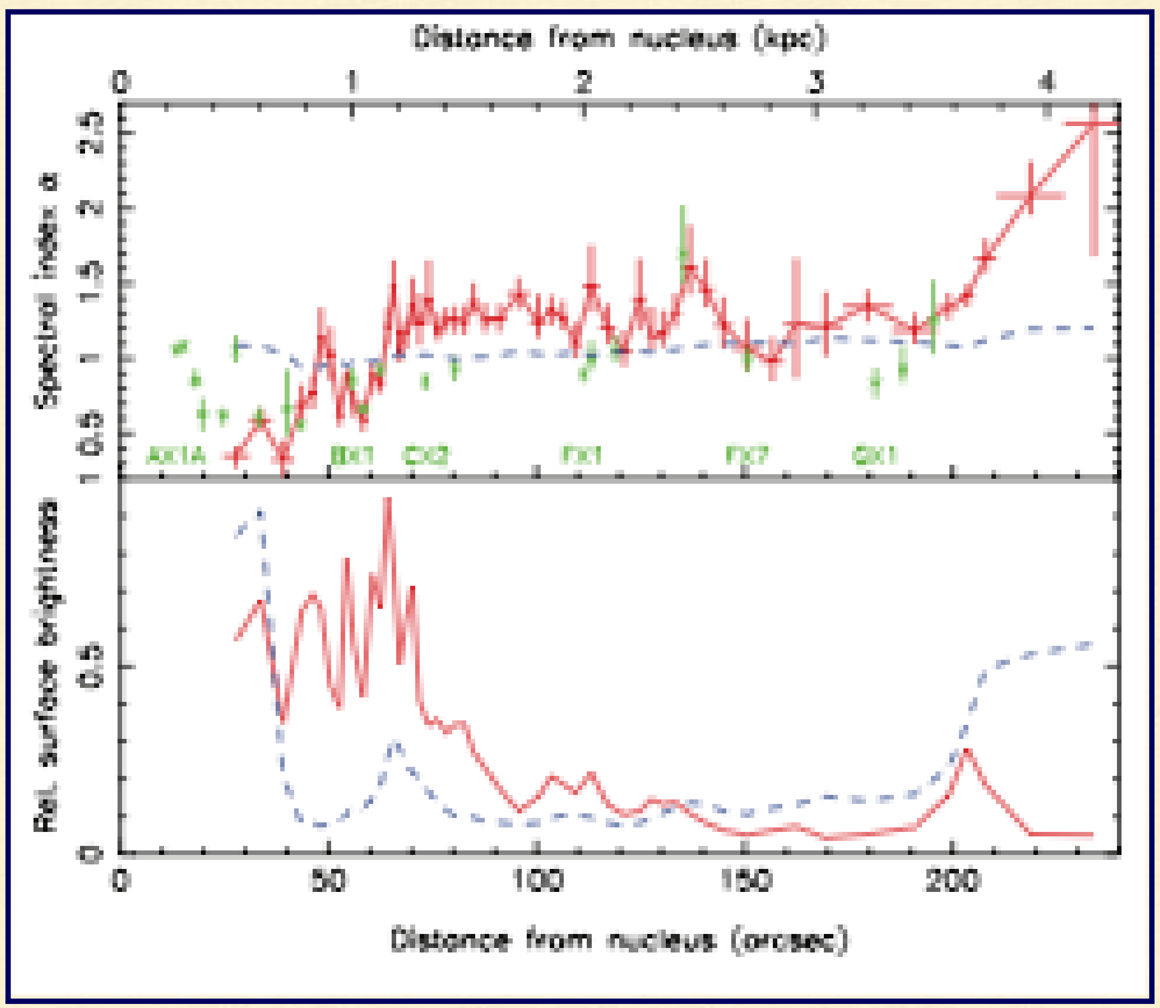
OUTLINE

- Motivation
- Numerical code - PLUTO
- Application to Jets.
- Spectral Evolution
- Outlook & Summary.





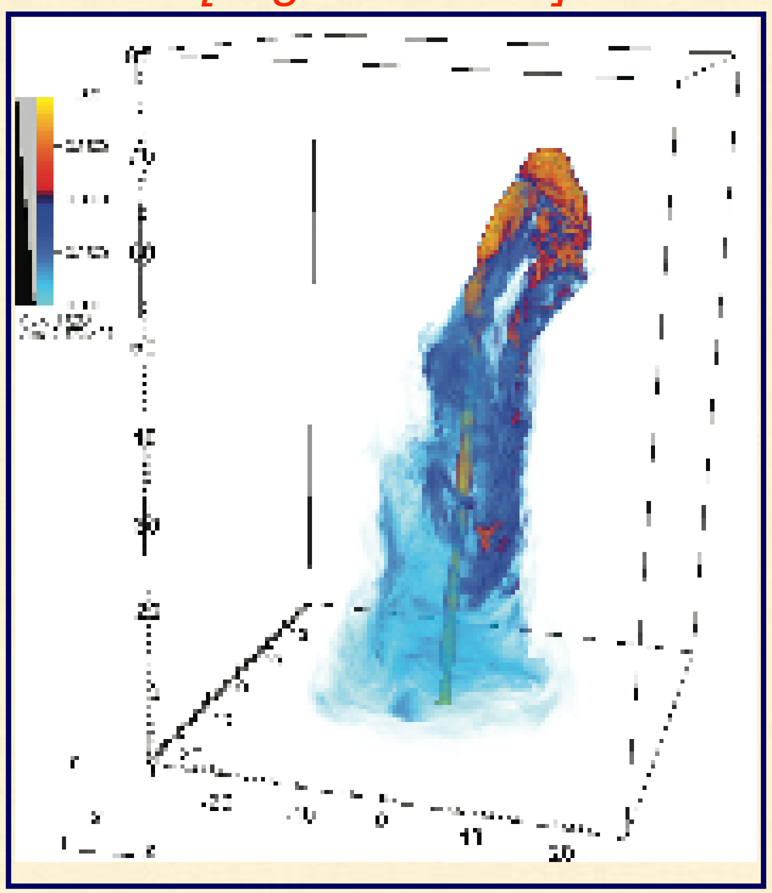
- *X-ray, optical, radio - Synchrotron electrons*
- *Spectral Index Variation with distance*
- *In Situ Particle Acceleration.*
  - Fermi I or Fermi II or both
- *Competition between loss mechanisms and Acceleration processes.*

Hardcastle, 2007

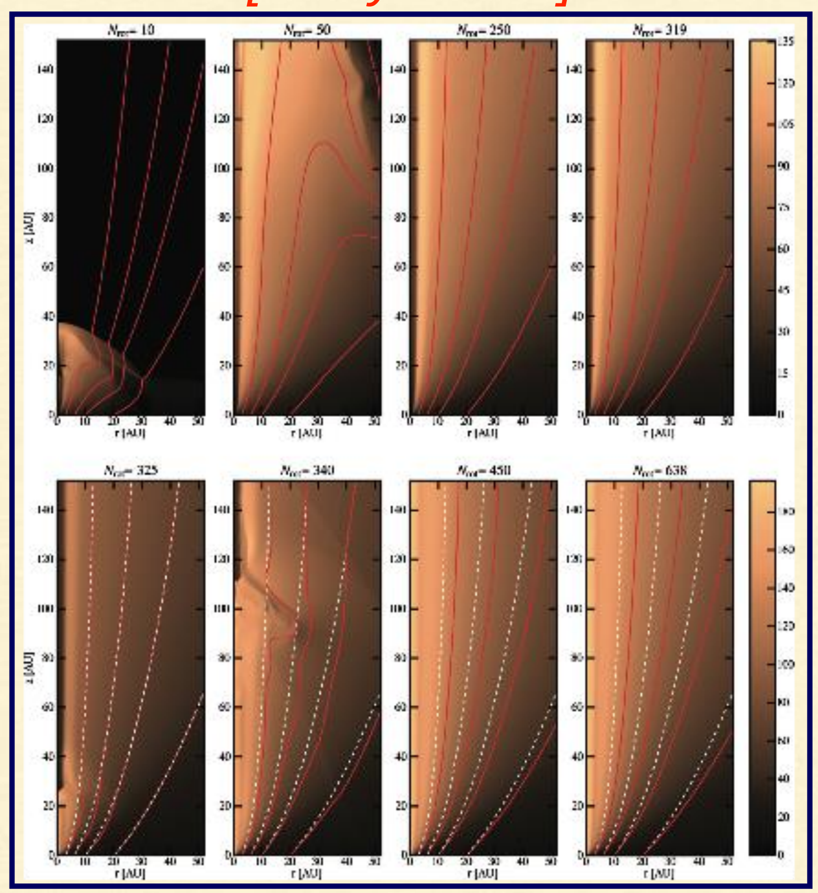
PLUTO code (Mignone 2007, 2012)

Grid based computational astrophysical code with multi-physics modules and scalable parallel code with adaptive mesh refinement.

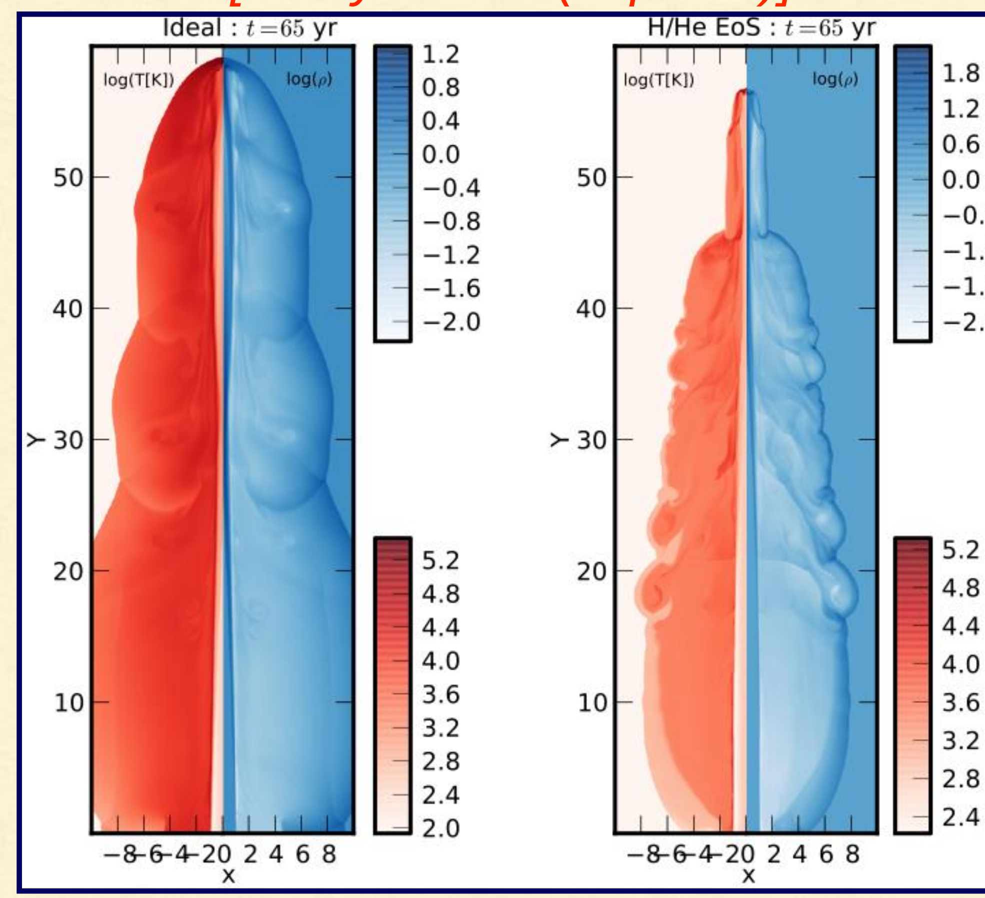
3D Relativistic MHD Jet [Mignone 2010]



Radiative MHD Jet from Massive stars [Vaidya 2011]



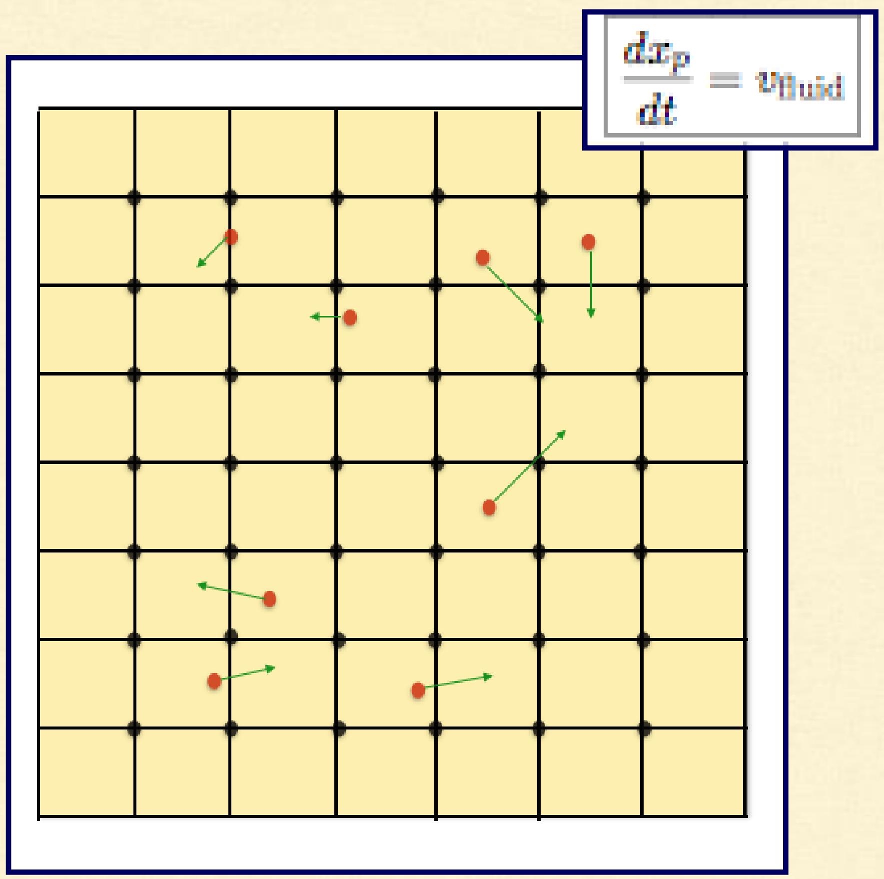
Young Molecular jets with chemistry/cooling [Vaidya 2015 (in press)]



An Hybrid Approach

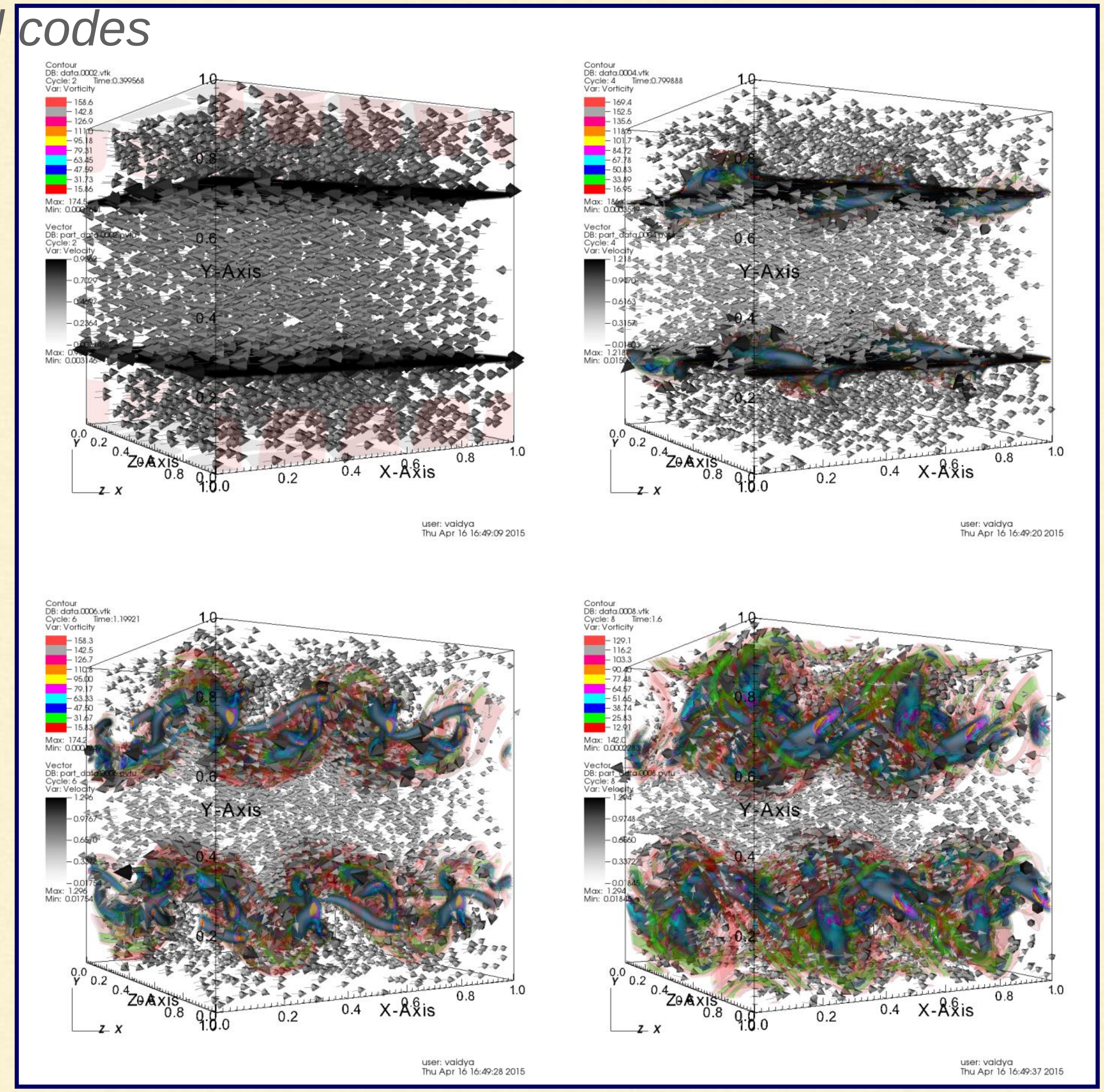
Lagrangian Particle dynamics in unison with Fluid flow on Eulerian grid.

- *Large scale studies with fluid based codes*
- *Particles Advect with fluid.*
- *Referred to as “Macro” Particles for spectral studies.*



$$\frac{dx_p}{dt} = v_{\rm fluid}$$

3D KH (Grid - 384^3) with 10^6 particles.



- *Low Power Radio Jets - Slower than its cousin FRII.*

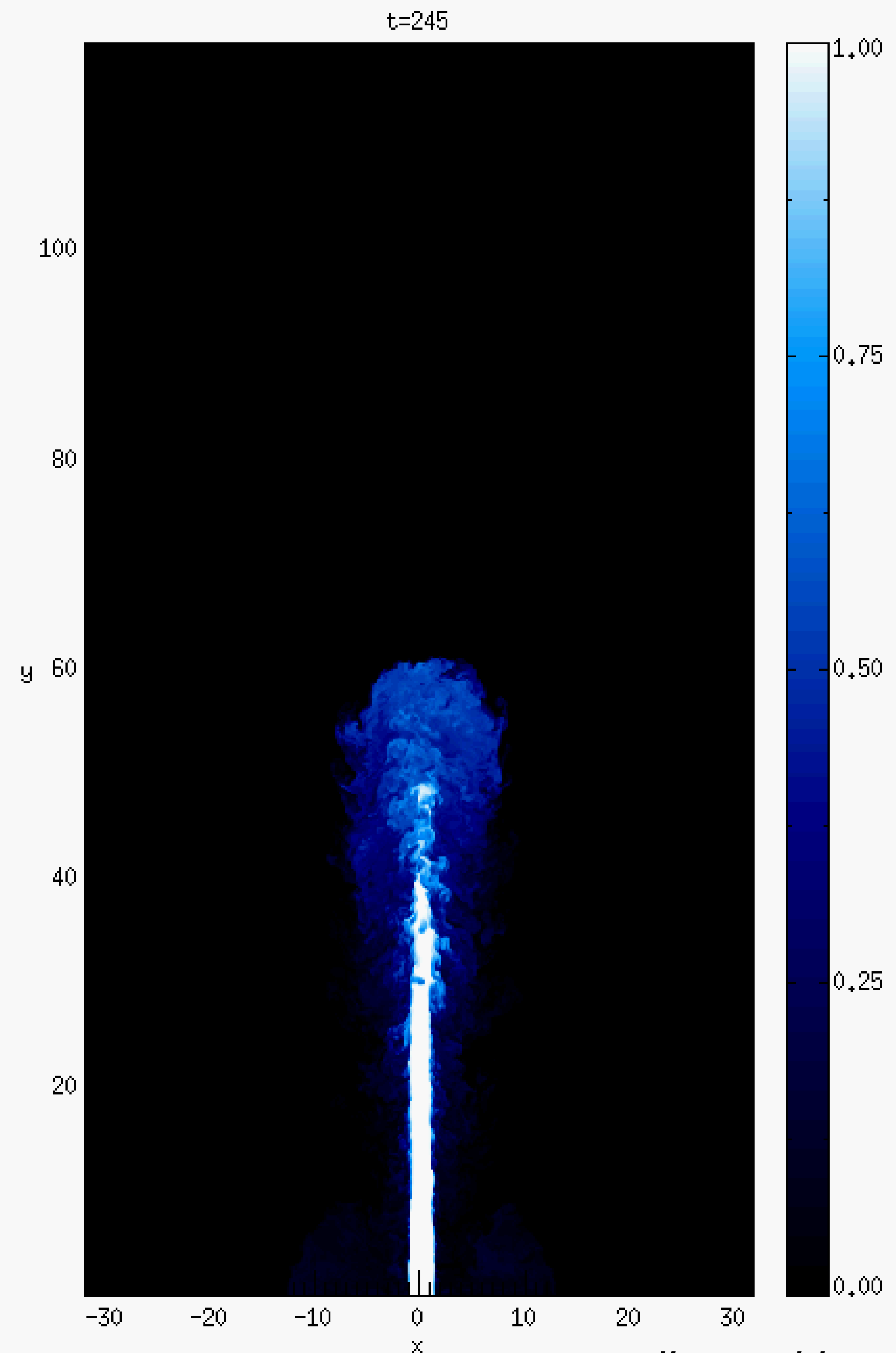
Numerical FRI Jet Model

- *Axisymmetric, Decelerate with distance (Giovaninni 2005, Laing & Bridle 2008) — Non-Relativistic*

- *Ambient Medium :*
  - *NFW like Galactic core profile*
  - *Jet is in pressure equilibrium with the ambient*
  - *Therefore : Temperature increases with height.*

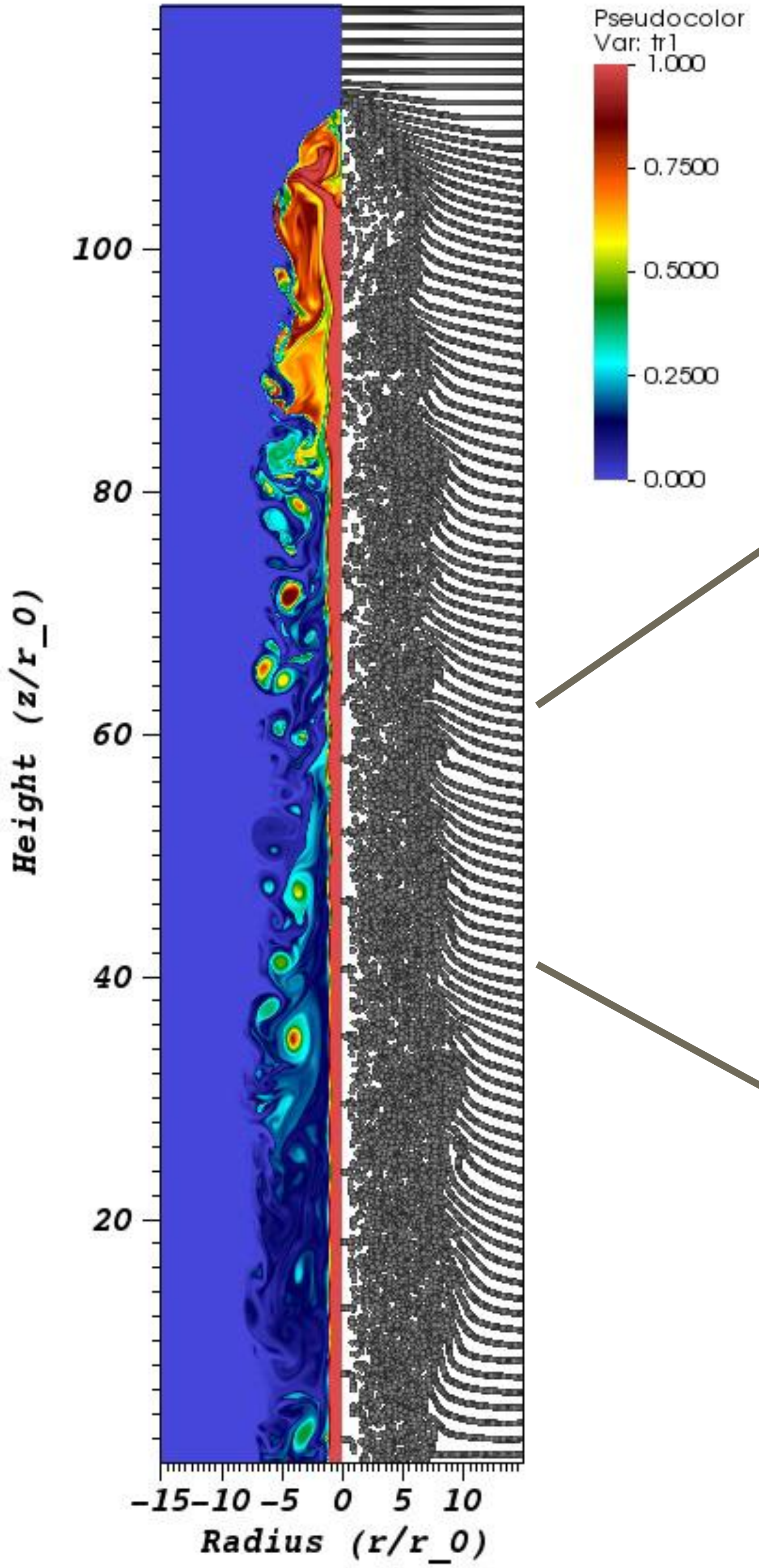
- *Jet Nozzle :*
  - *Under-dense (eta = 0.01)*
  - *Radius at the Nozzle r_0 = 100 pc.*
  - *Ejected with a Mach Speed M = 4.*
  - *Magnetic Field - Few 100 microG at kpc scales ??? (Gabuzda, 2010)*

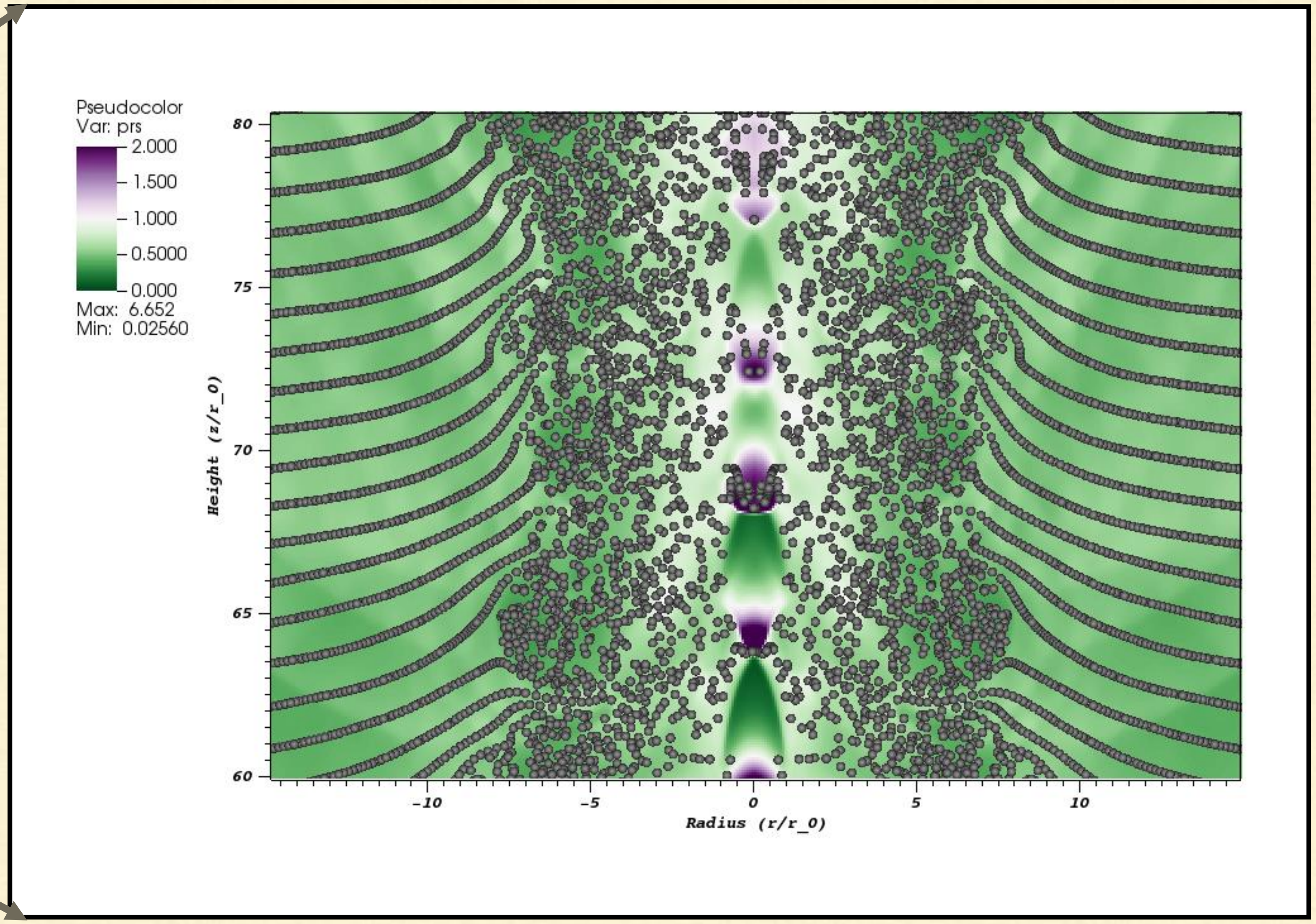
- *Particles :*
  - *> 10^5 "Macro" Particles*
  - *Initial Uniform distribution in the ambient medium*
  - *Particles injected at regular time intervals*



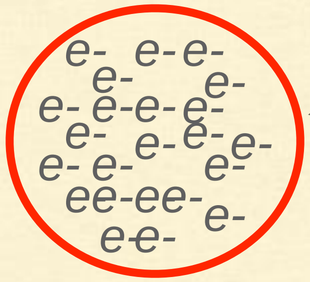
Massaglia et al in prep

Particle dynamics : AGN jets





Spectral Evolution : “Macro” Particles



Grid in Particle Energy Space — Initial E_{min} to E_{max} with log-spaced bins.
Particle Density — Initial Power Law distribution $N(E) = N_0 E^{-p}$; $p = 3$

Spectral evolution using the Fokker-Planck Equation : For each “Macro” Particle
(Skilling 1975 , Blandford & Eichler 1987, Krulls & Achterberg 1994, Casse & Marcowidth 2003)

$$\frac{\partial f}{\partial t} = -(\mathbf{u}.\nabla)f + \frac{1}{3}(\nabla\cdot\mathbf{u})p\frac{\partial f}{\partial p} + \nabla_i(D_{ij}\nabla_j f) + \frac{1}{p^2}\frac{\partial}{\partial p}\left(D_{pp}p^2\frac{\partial f}{\partial p} + a_{syn}p^4 f\right)$$

Adiabatic (de-)compression.

Synchrotron Losses

$$a_{syn} = \frac{\sigma_T B_\perp^2}{6\pi m_e^2 c^2}$$

Second Order Fermi (sub-grid physics??)

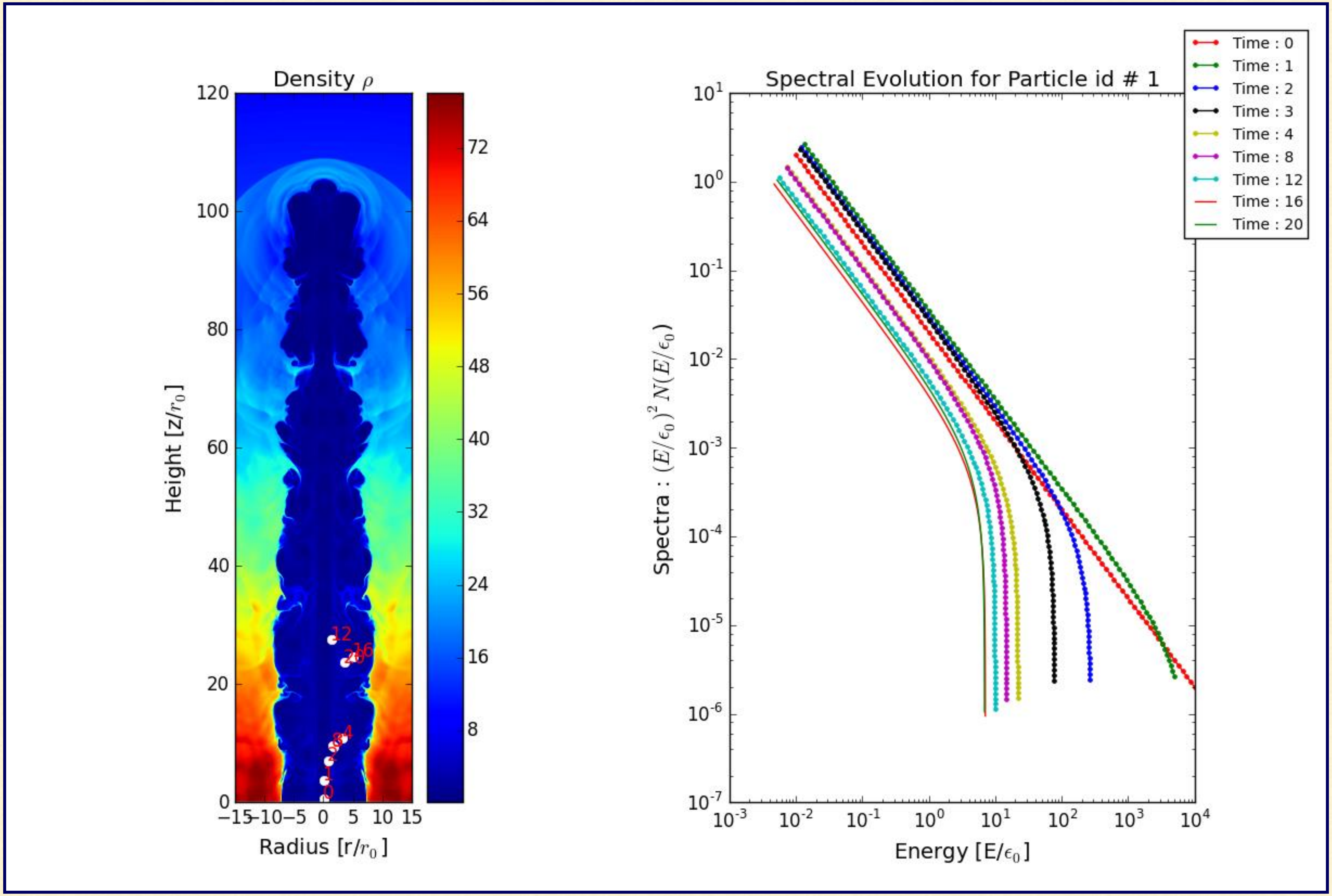
$$D_{pp} = 0$$

First Order Fermi : Asymptotic Limit

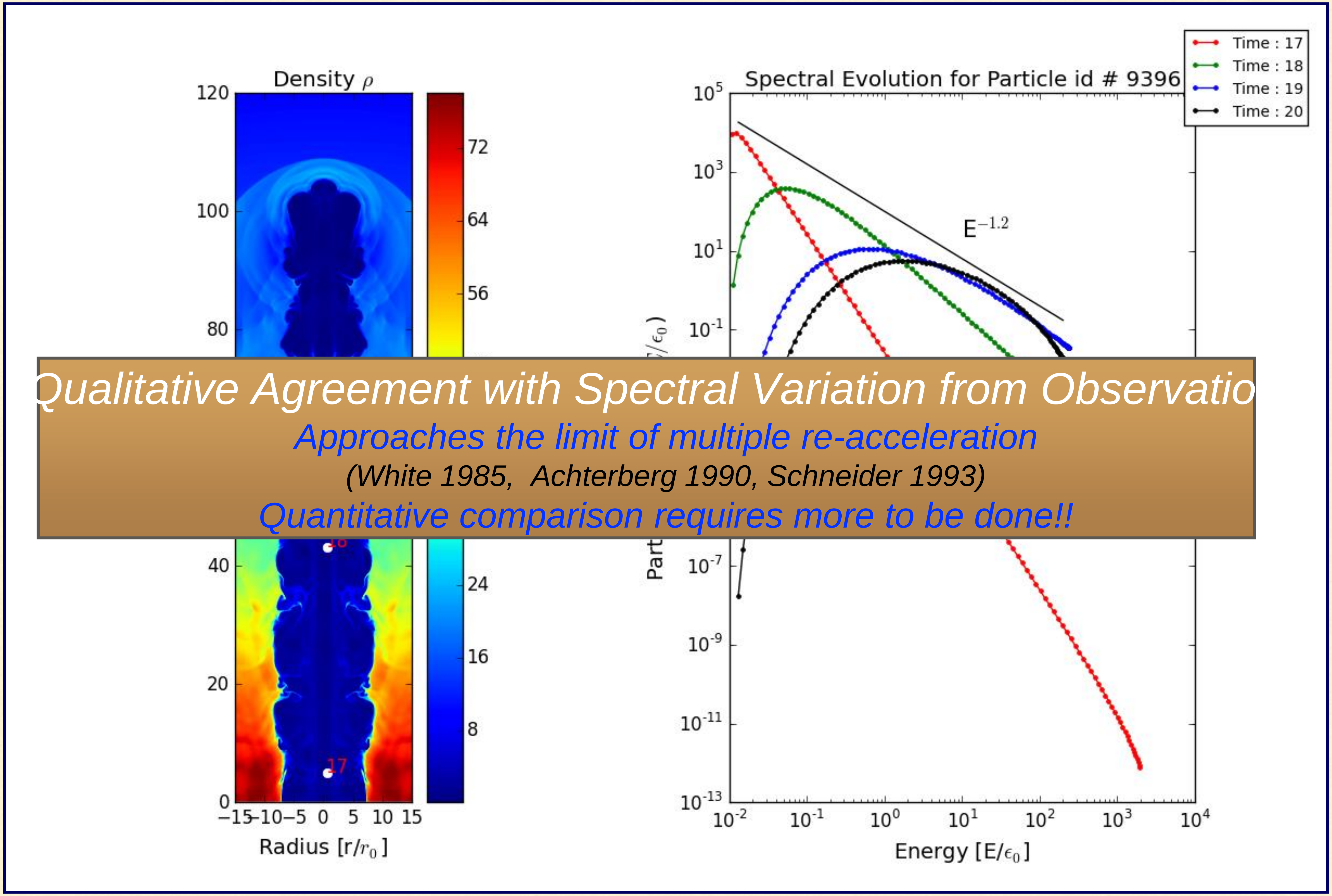
$$f_+(p) = bp^{-q}\int_0^p p'^{(q-1)} f_-(p')dp'; \quad b = \frac{3u_1}{u_2 - u_1}; \quad q = \frac{3r}{r-1}$$

(Melrose & Pope 1993, Micono 1999, Parker 2014)

Dominant Losses !



Diffusive Shock Acceleration at work



Qualitative Agreement with Spectral Variation from Observatio

Approaches the limit of multiple re-acceleration

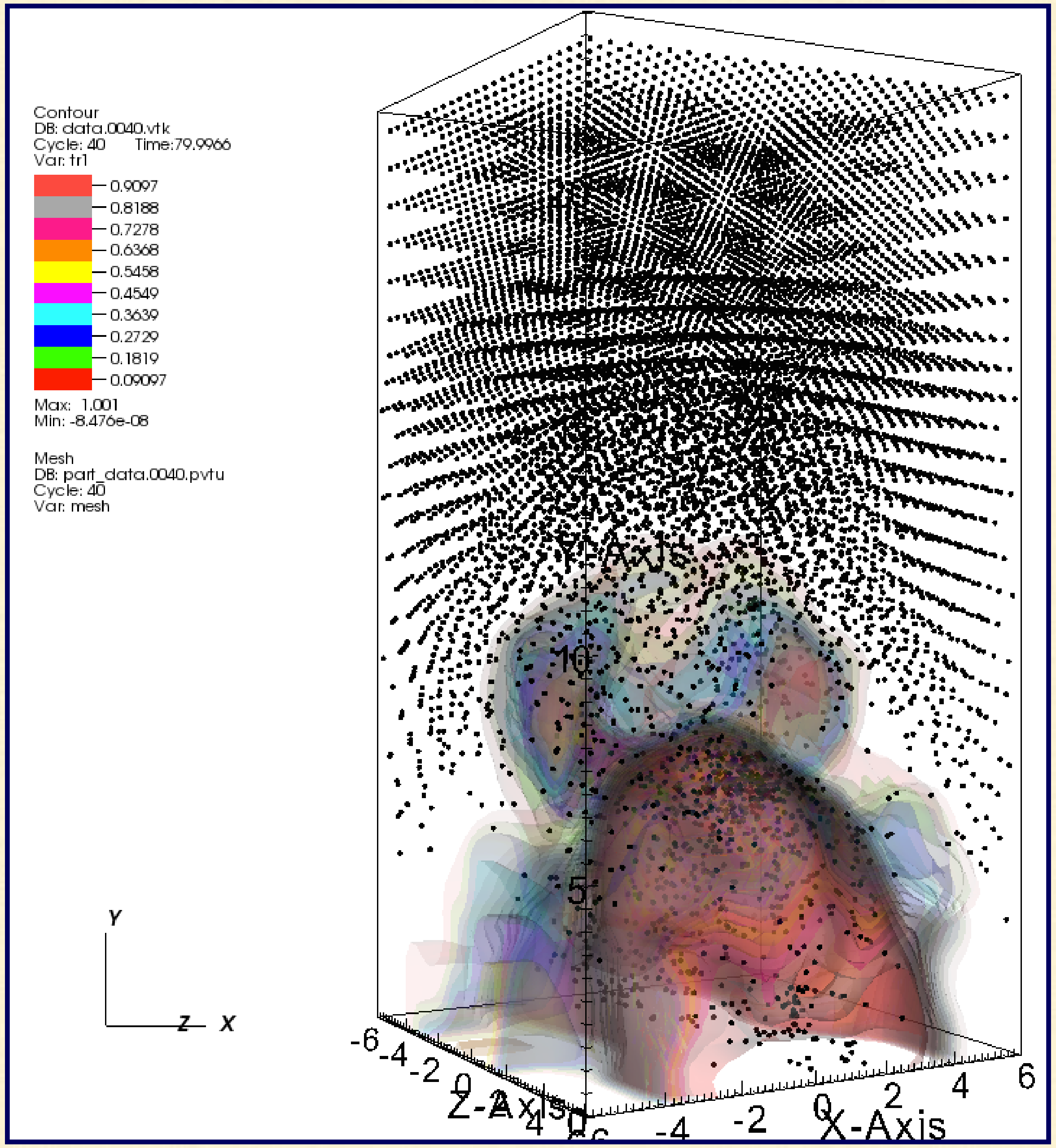
(White 1985, Achterberg 1990, Schneider 1993)

Quantitative comparison requires more to be done!!

Work in Progress…

- *Account for High energy cutoff and some leakage model.*
- *Emissivity from Spectra: Direct Comparison with Observations (Polarization)*
- *Sub-grid Prescription for microscopic Turbulent Acceleration processes: Magnetic-Reconnection*

  (Sironi 2015, Sironi & Spitskovski 2014)
- *Extension to 3D Simulations: Non-axisymmetric Instability, Weaker shocks then in 2.5D.*
- *Account for Up-scattering of photons : TeV Gamma rays. from Blazars (IC Emission, sub-pc scales)*



Summary

- *Developed an hybrid code - Combining Grid-based fluid with Lagrangian Particles for various astrophysical applications :*
  - *Particle Acceleration in AGN jets on large scales, can be even extended to Supernov*
  - *Particles can be treated as dust grains to study mixing in accretion disks.*

- *Particle dynamics in MHD Jets -*
  - *Particles quickly mix in the Kelvin Helmholtz vortices that form on the edges of the jet.*
  - *Injected particles are effected by strong internal shocks.*

- *Spectral Evolution at kpc scales -*
  - *Losses due to synchrotron cooling becomes for particles is less violent environments*
  - *At the axis, the multiple re-acceleration at internal shocks makes DSA works very effectively*

- *Comparison with Observations -*
  - *Account for Particles high energy limit — particles escape.*
  - *Include stochastic processes to account for turbulent processes*
  - *Include losses due to IC emission specially for regions close to core.*