MFPO, Cracow - May 20, 2010

Star formation and turbulence: from sub-pc to kpc scales

Reinaldo Santos de Lima
Elisabete M. de Gouveia Dal Pino

IAG-USP, Brazil

Collaborators

Alex Lazarian (U. Wisconsin)

Marcia M. R. Leao (IAG-USP)

Diego Falceta-Goncalves (UCS)

Jay Gallagher (U. Wisconsin)

Grzegorz Kowal (IAG-USP)

Turbulence on star formation

at pc scales

Turbulence on star formation @ pc

MHD turbulence: important for ISM structuring and **star formation**

A related key question:

How is **magnetic field diffused** outward to allow cloud collapse?

The magnetic flux problem

Diffusive mechanisms usually invoked:

Ambipolar diffusion (AD)

Hyper resistivity: nature? (Shu et al. 2006)

Which one dominates?

AD expected to dominate late stages of collapse (when gas partially ionized);

Early stages? Controversy (see Shu et al. 2006, and papers by Crutcher and Mouschovias)

New scenario

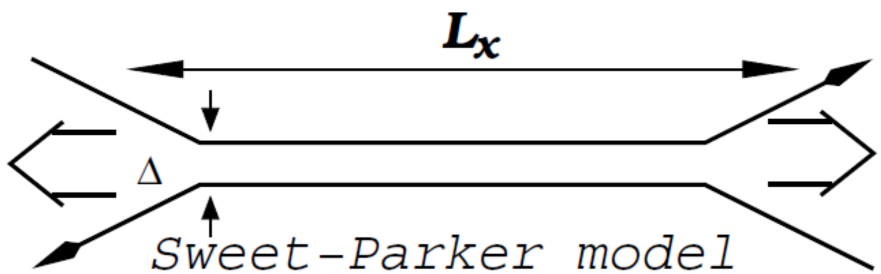
Diffusion through turbulent reconnection.

Due to turbulence: field lines reconnect, changing their topology and then magnetic flux escapes from denser regions.

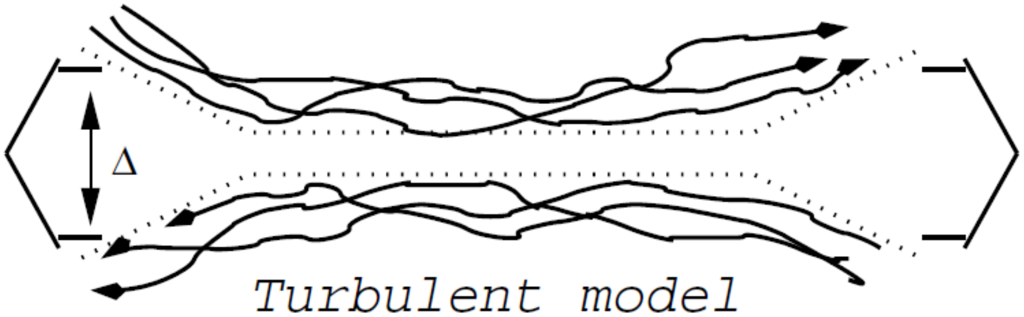
➔ *Lazarian (2005), Santos-Lima et al. (2010)*

Underlying physics

Turbulent reconnection:



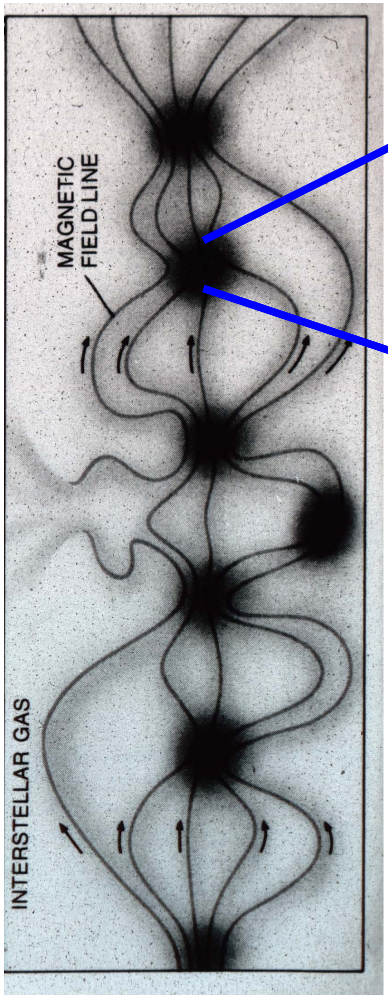
- Lazarian & Vishniac (1999) fast reconnection model (Alex's talk)



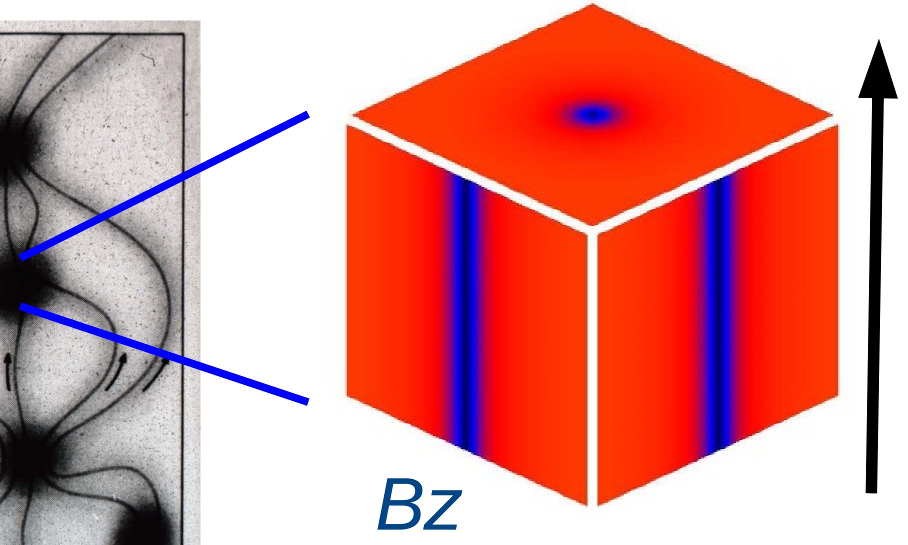
- Recently tested in numerical simulations by Kowal et al. (2009) (Grzegorz's talk)

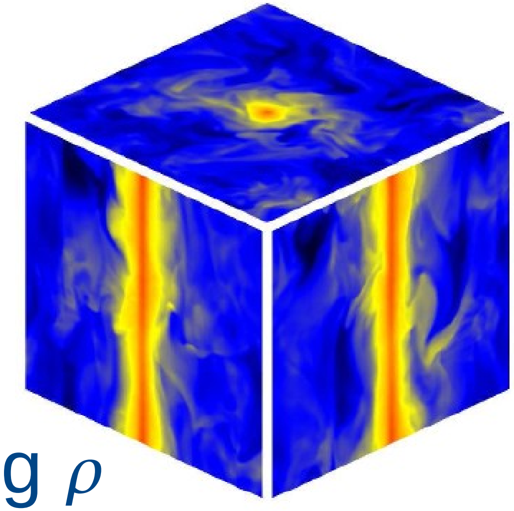
Magnetic field diffusion in gravitating clouds: 3D simulations

- One fluid model;
- Gravitational potential with cylindrical symmetry;
- Periodic boundary conditions;
- Isothermal EOS;
- Magneto-hydrostatic equilibrium / out-of-equilibrium homogeneous fields;
- **Injection of subAlfvenic turbulence**



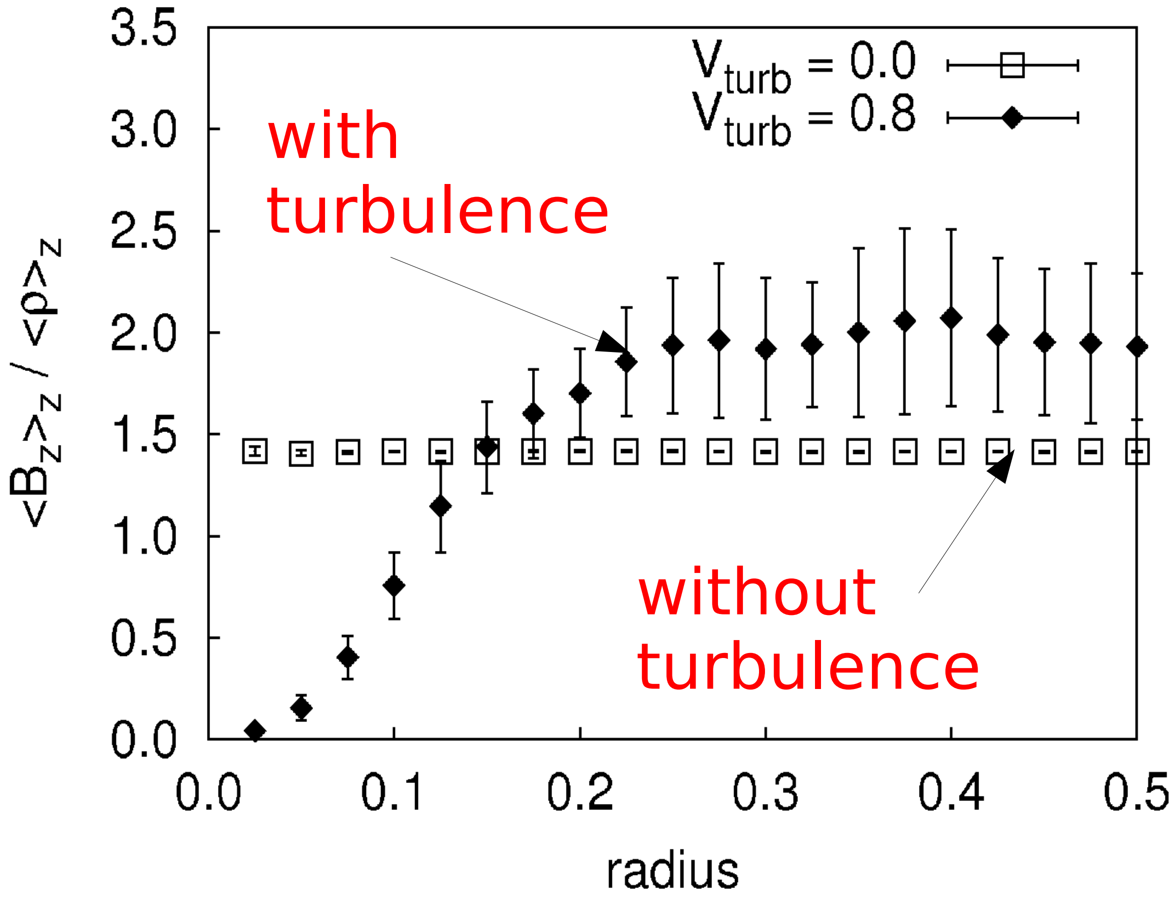
From **Crutcher** (IAU2009 JD15)





Magnetic field diffusion in gravitating clouds: 3D simulations

(starting out-of-equilibrium)



- Removal of magnetic flux from the central regions (strong-gravity);
- Gas inflow into the central region;
- **Reduction of the flux-to-mass ratio in the central region.**

(Santos-Lima et al., ApJ, 2010)

Main results

Higher efficiency of diffusion for:

- Higher gravity

$$\beta = 1,\ V_{rms} = 0.8$$

$V_{A,0}$	A	$\eta_{turb}/V_{rms}l_{inj}$
1.4	0.6	$\lesssim 0.015$
1.4	0.9	≈ 0.03
1.4	1.2	≈ 0.09

- Higher beta

$$A = 0.9\ (\Phi = -A/r^2),\ V_{rms} = 0.8$$

β	$V_{A,0}$	$\eta_{turb}/V_{rms}l_{inj}$
0.3	2.4	≈ 0.03
1.0	1.4	≈ 0.03
3.3	0.8	≈ 0.06

(Models starting from magneto-hydrostatic equilibrium with beta constant)

Main results

Higher efficiency of diffusion for:

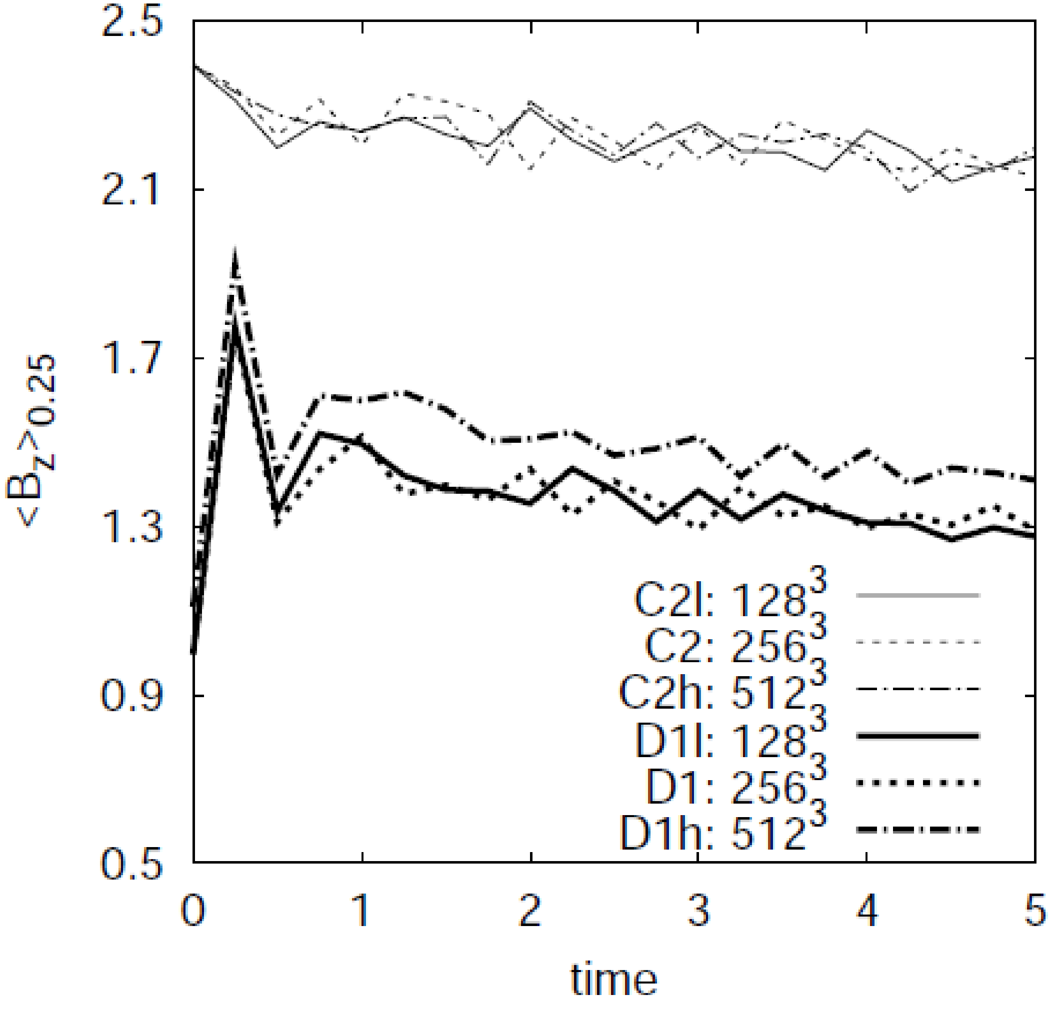
- Higher turbulent velocity

$\beta = 1, A = 0.9$

$V_{A,0}$	V_{rms}	$\eta_{turb}/V_{rms}l_{inj}$
1.4	0.8	≈ 0.03
1.4	1.4	$\approx 0.18 - 0.36$
1.4	2.0	$\gtrapprox 0.37$

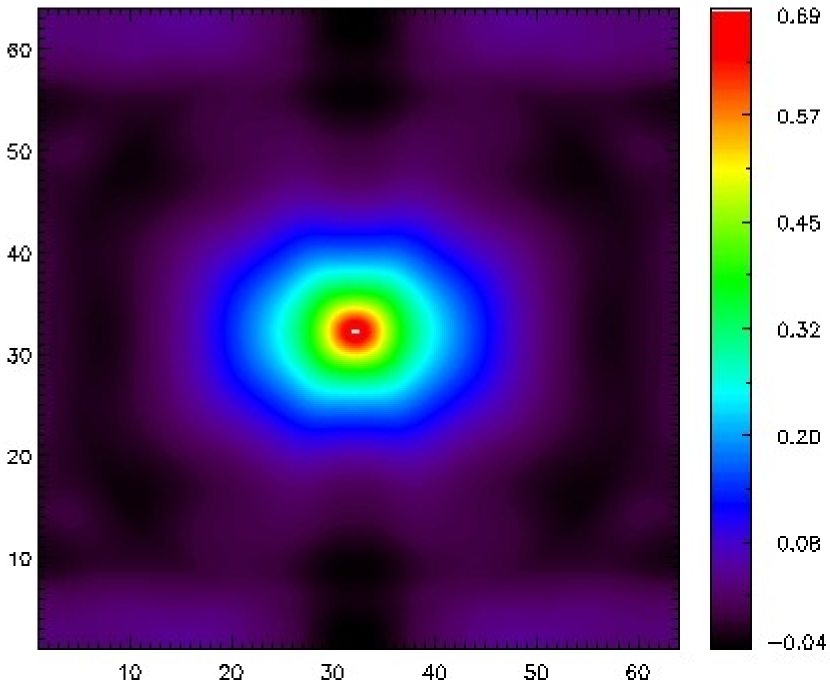
(Models starting from magneto-hydrostatic equilibrium with beta constant)

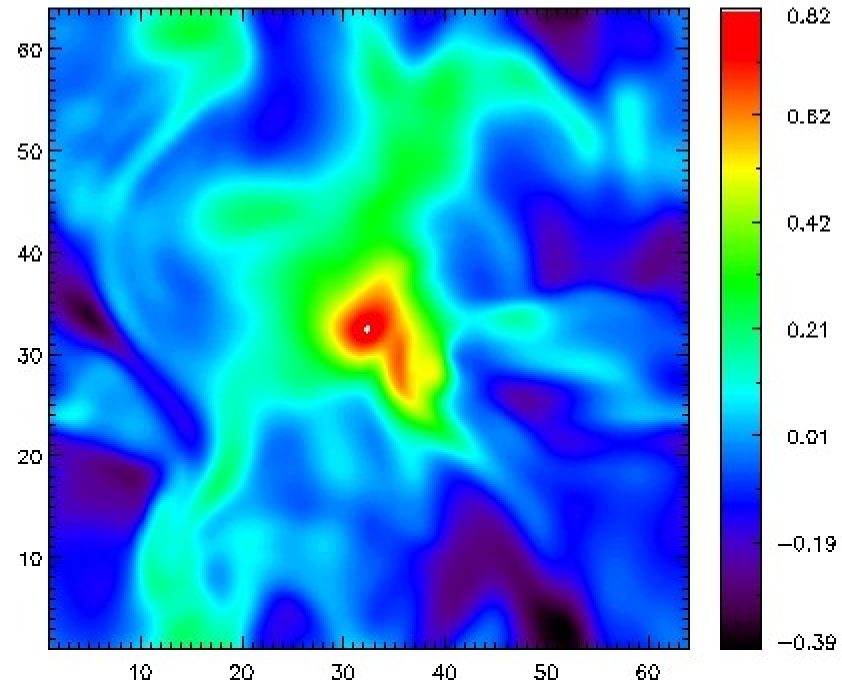
Effects of numerical resolution on the turbulent diffusion



Self-gravitating clouds

Self-gravity + external potential ($\sim 1/r^2$)

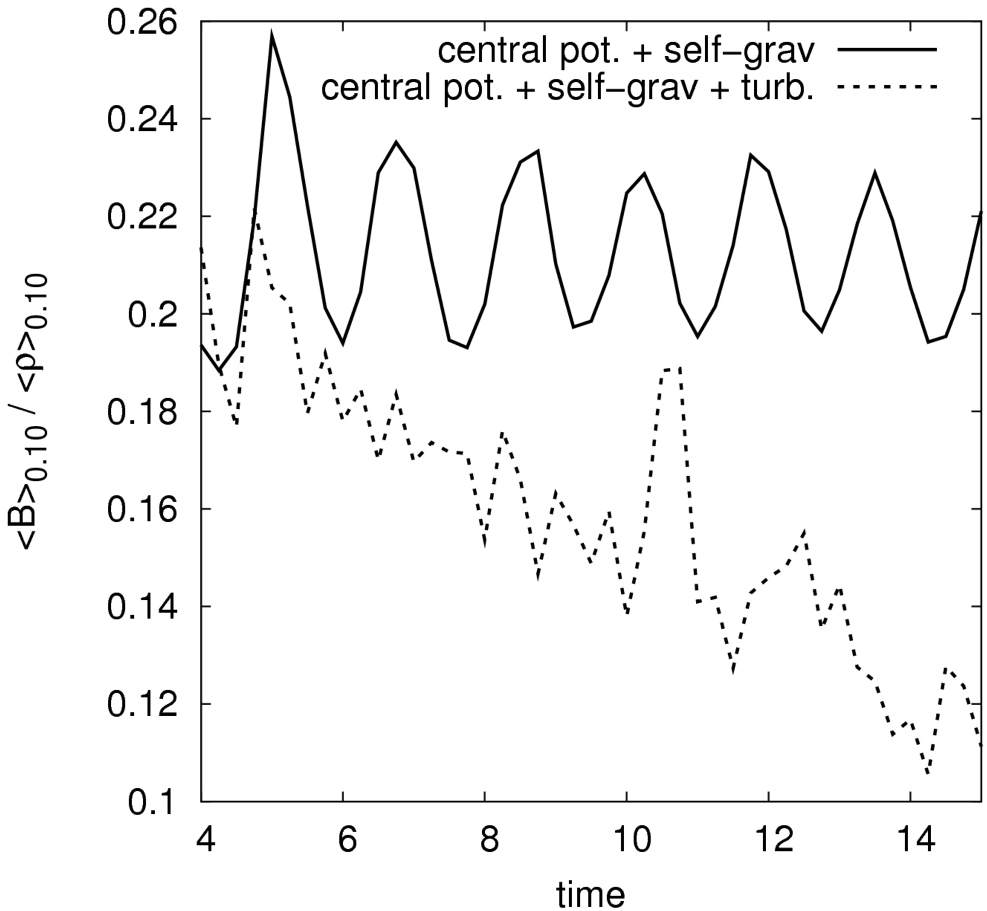




see poster by Leao et al.

Self-gravitating clouds

$\beta_0 = 3$



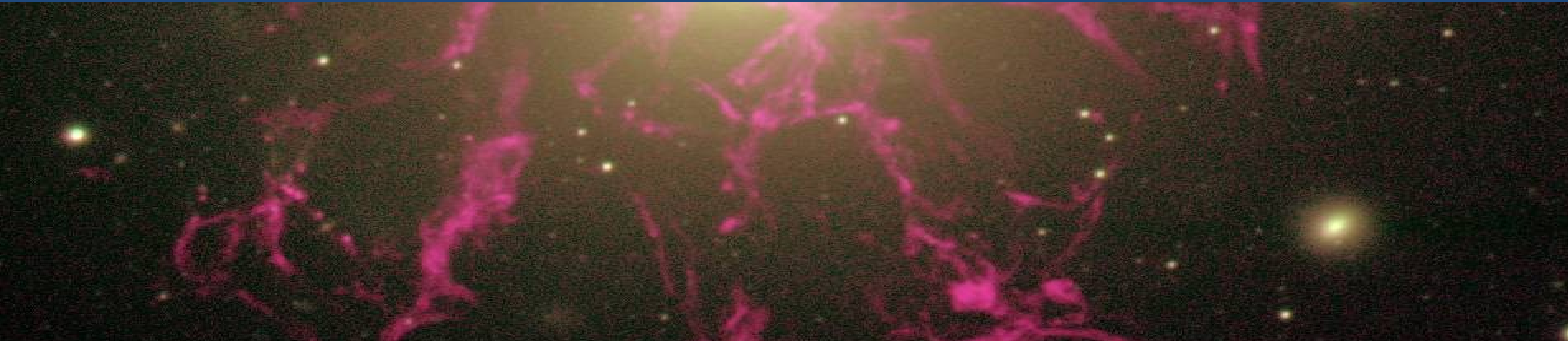
without turbulence

with turbulence

Efficient removal of B-flux from the central region

Star formation effects on turbulence and structuring:

at kpc scales



Star formation turbulence feedback

Star formation feedback is a fundamental issue in the evolution of galaxies.

Galactic winds from star forming galaxies are known to be driven by **star formation/SN turbulence**.

We explore the role of star formation/SN turbulence in even larger scales: cores of galaxy clusters.

Perseus: brightest galaxy cluster in X-ray

The Perseus Cluster—Abell 426

distance 75 Mpc—1 arcsec = 370 pc

L_B= 3E10 L_{sun}

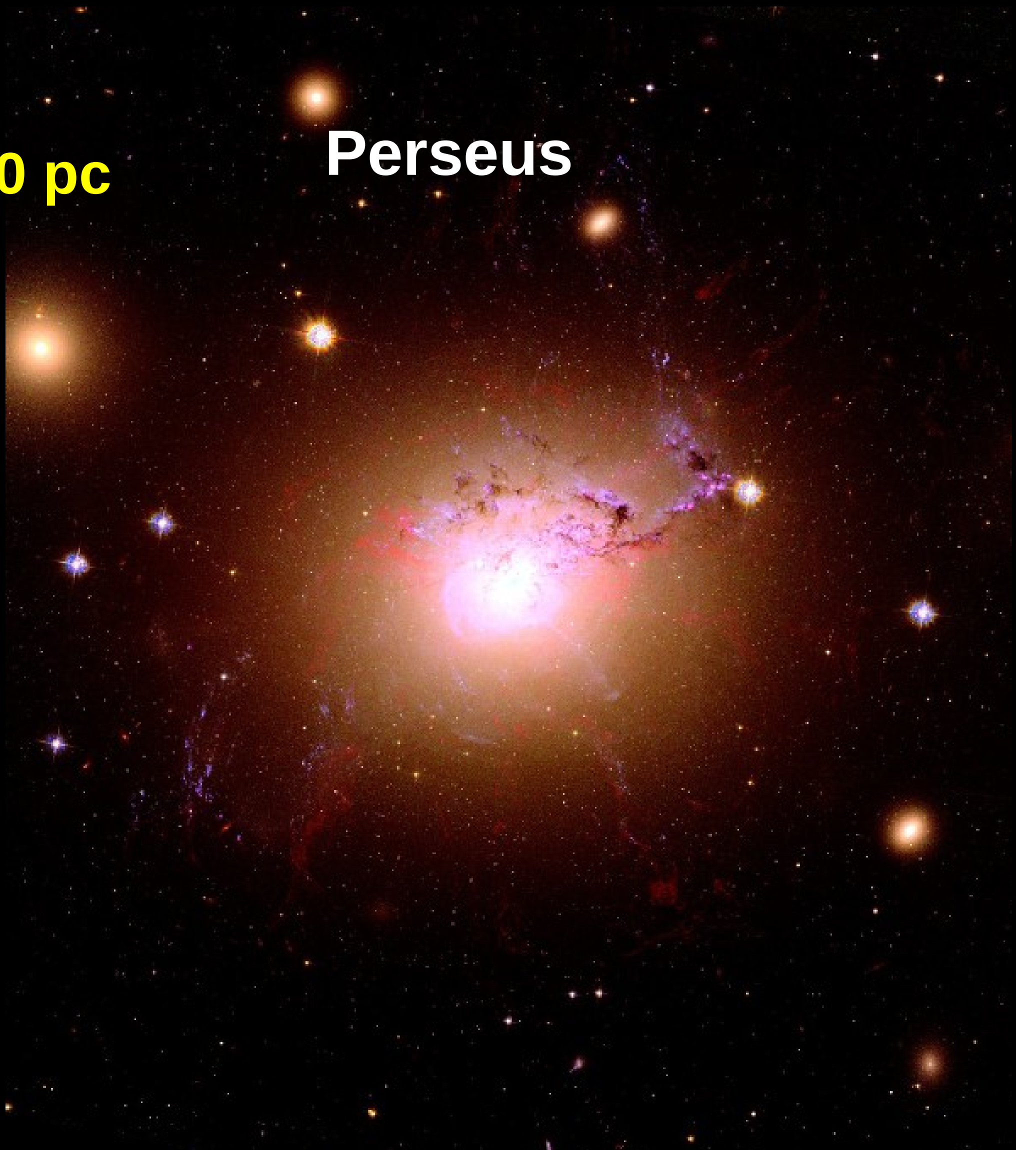
➔ M(*) ~ (few) E11 M_{sun}

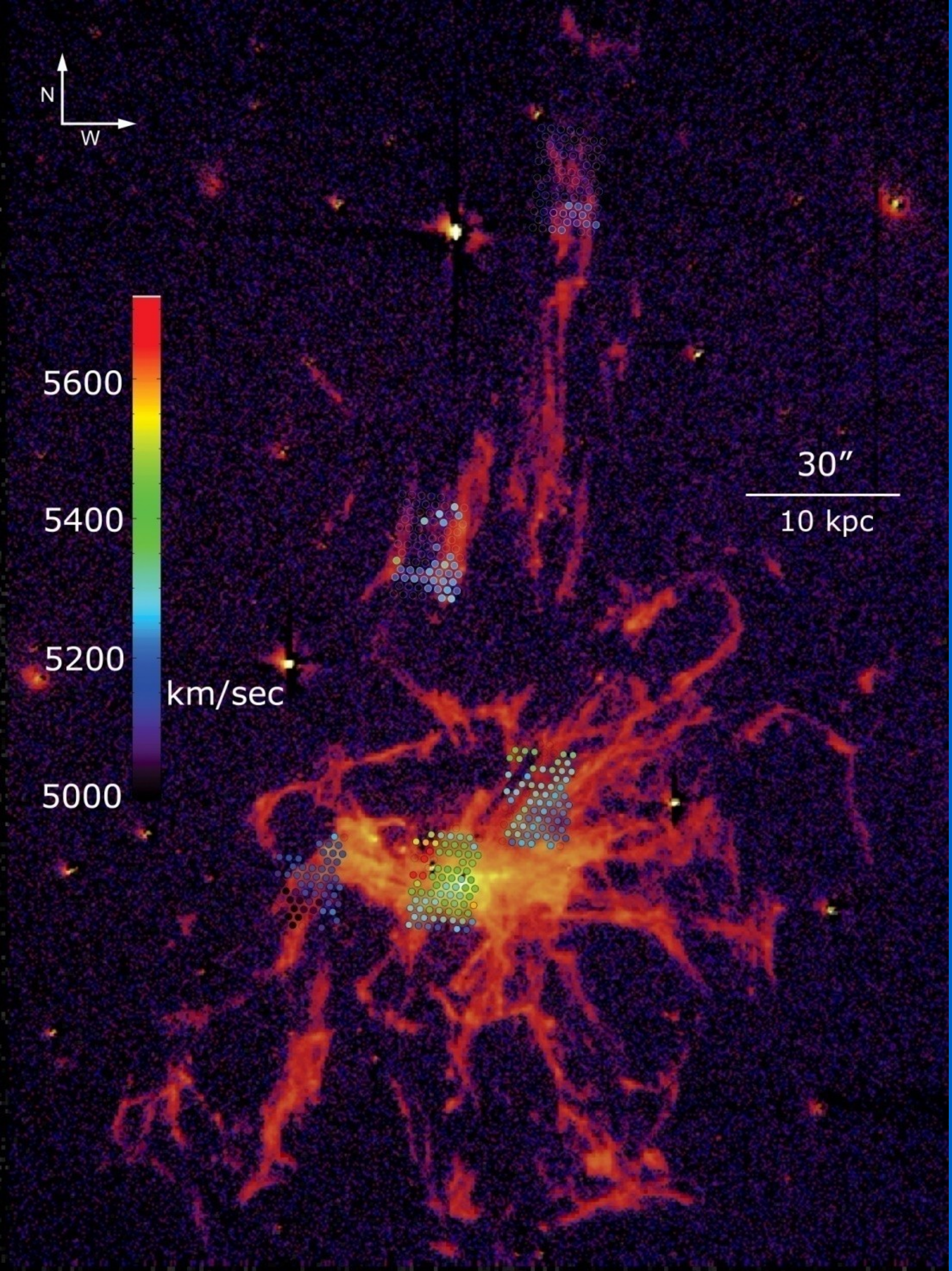
L_X = 3E45 erg/s

M(gas) ~ 7E13 M_{sun}

M(dyn) ~ 1E15 M_{sun}

Virial radius ~ 2.5 Mpc





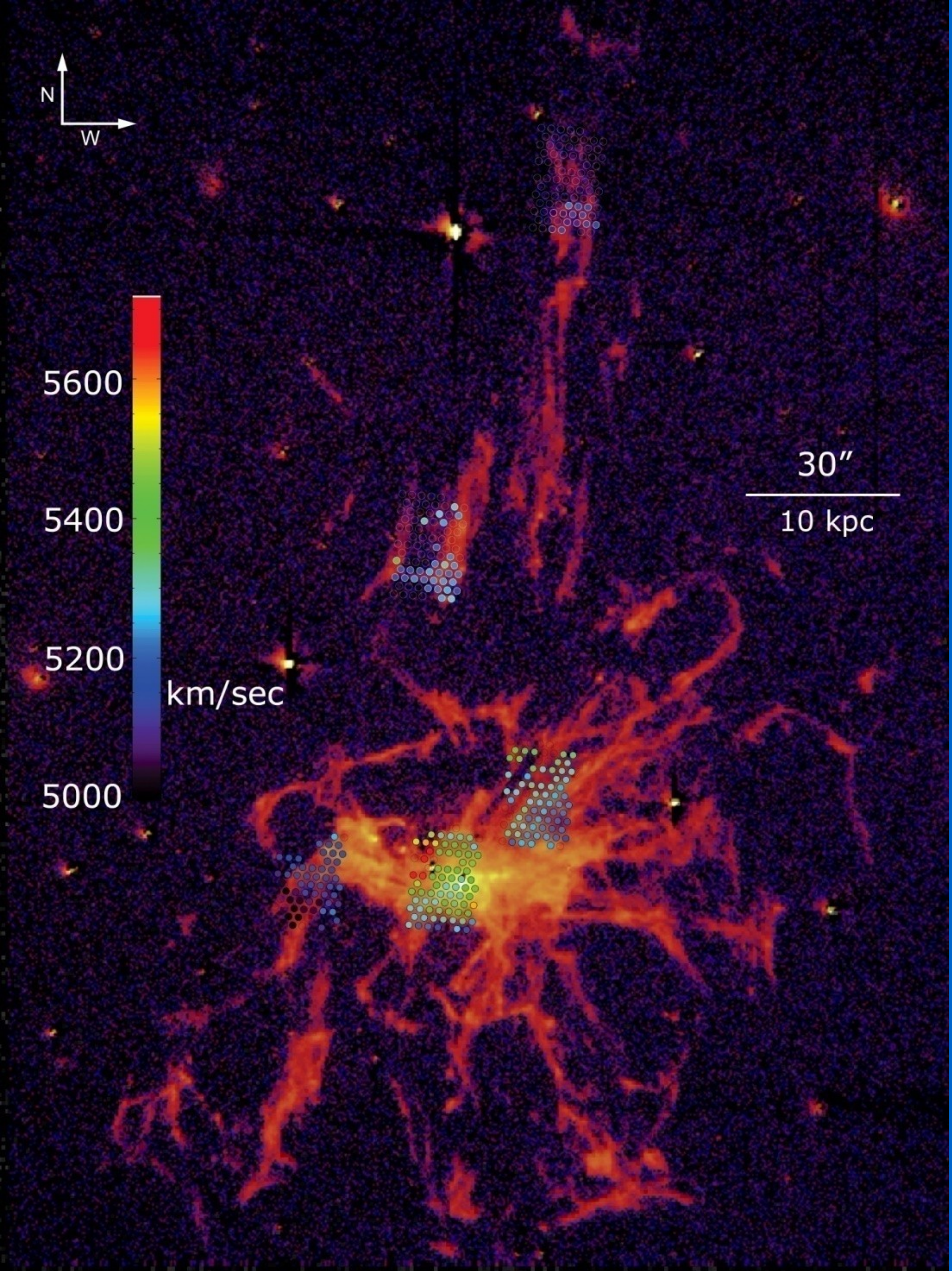
Filaments coming out from central galaxy (NGC 1275):

Hα+[NII] & stellar continuum

V(fil) ~200 km/s << c_s(IGM)

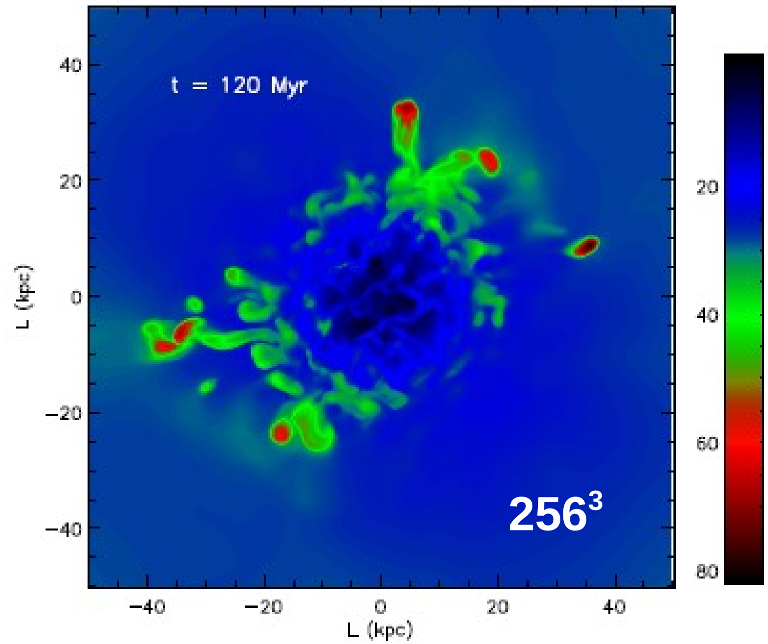
E(fil) ~ M(fil)$\langle v^2 \rangle$ > 4e57 erg

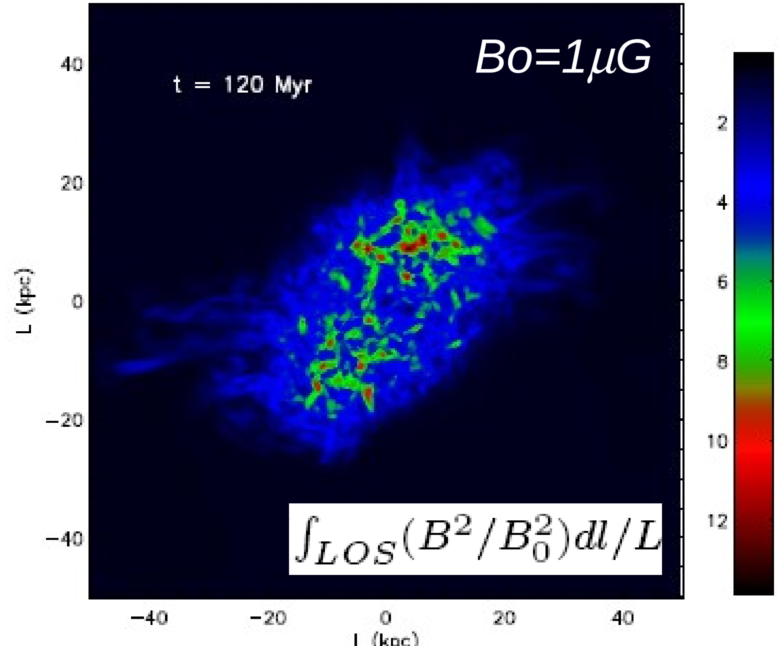
Cigan, Gallagher et al. 2009
Fabian et al. 2009



What is the role of star formation/SN-driven turbulence in filament-loops formation?

MHD simulations of central region of Perseus





MHD turbulence due to SF:

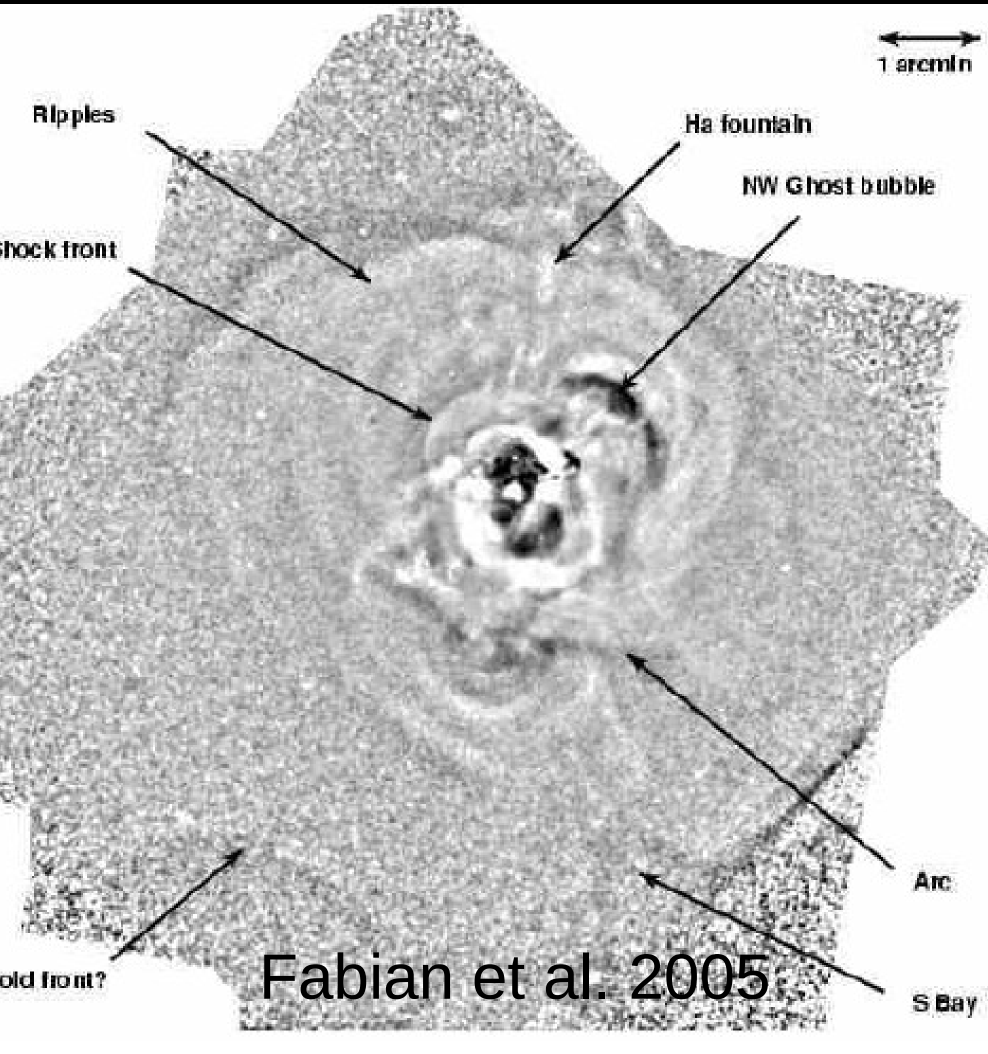
0.1 SN/yr – 10^{56} erg/Myr
Injected within 5 kpc:
$1 < L_{inj} < 3$ kpc

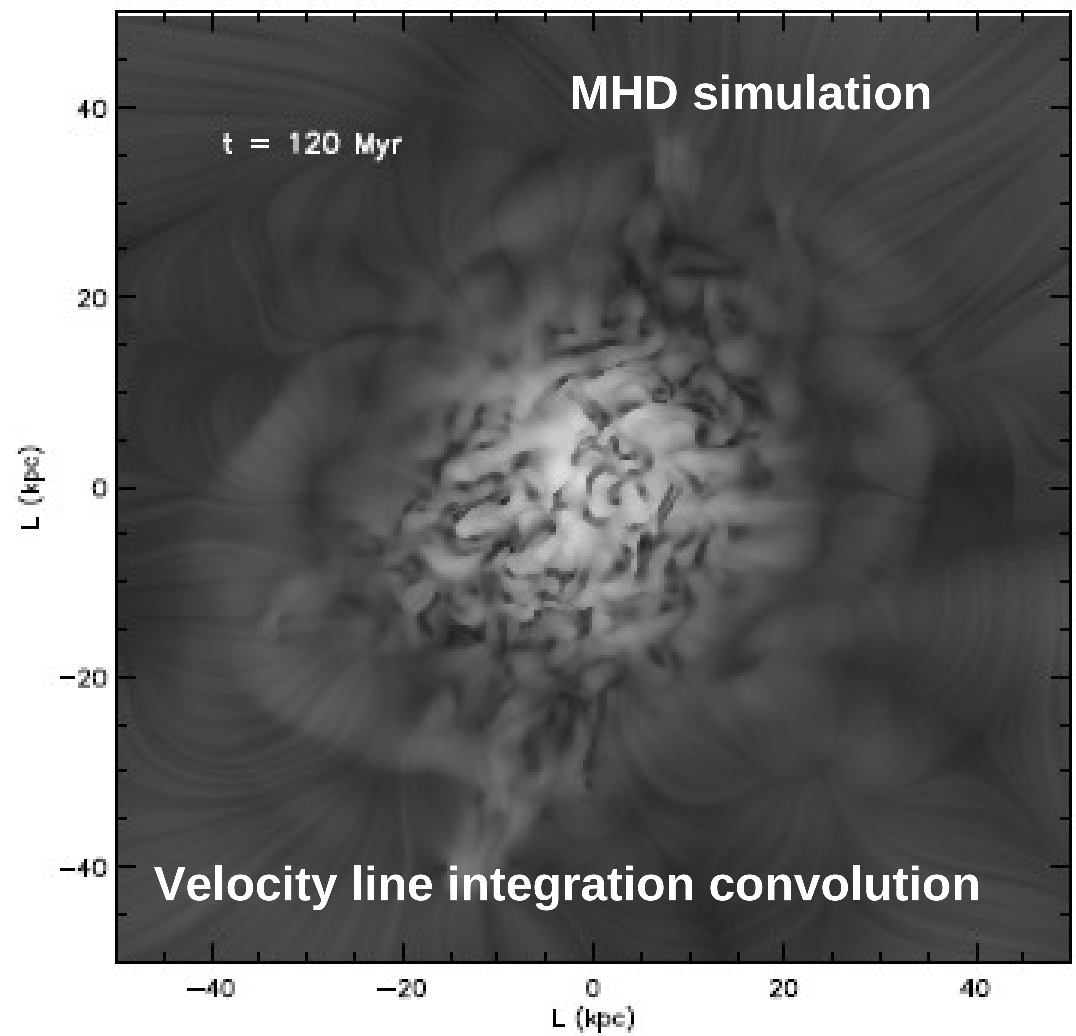
~ Radial filaments:

< 40 kpc
n = 0.01-0.04 cm^{-3} (10-100na)
v = 100-500 km/s
B dragged and
compressed: 5-20μG
(comparable to
Fabian et al. 2008)

Falceta-Goncalves, de Gouveia Dal Pino,
Galagher, Lazarian, ApJ lett. 2010a

SF-SN turbulence: could explain isotropic ripples and weak shocks

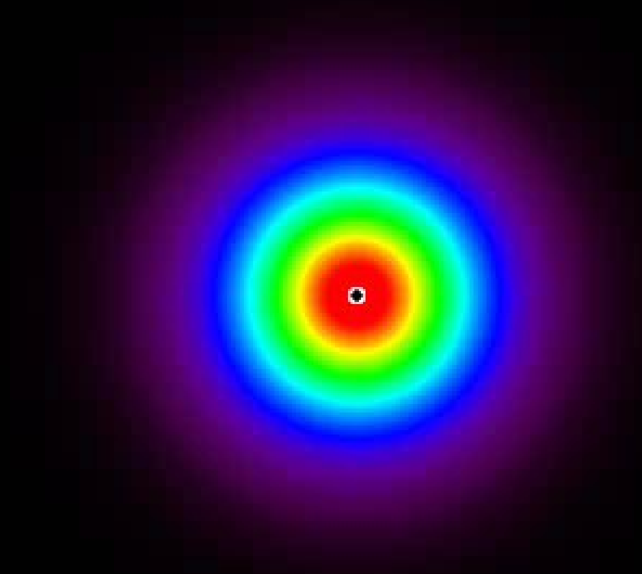




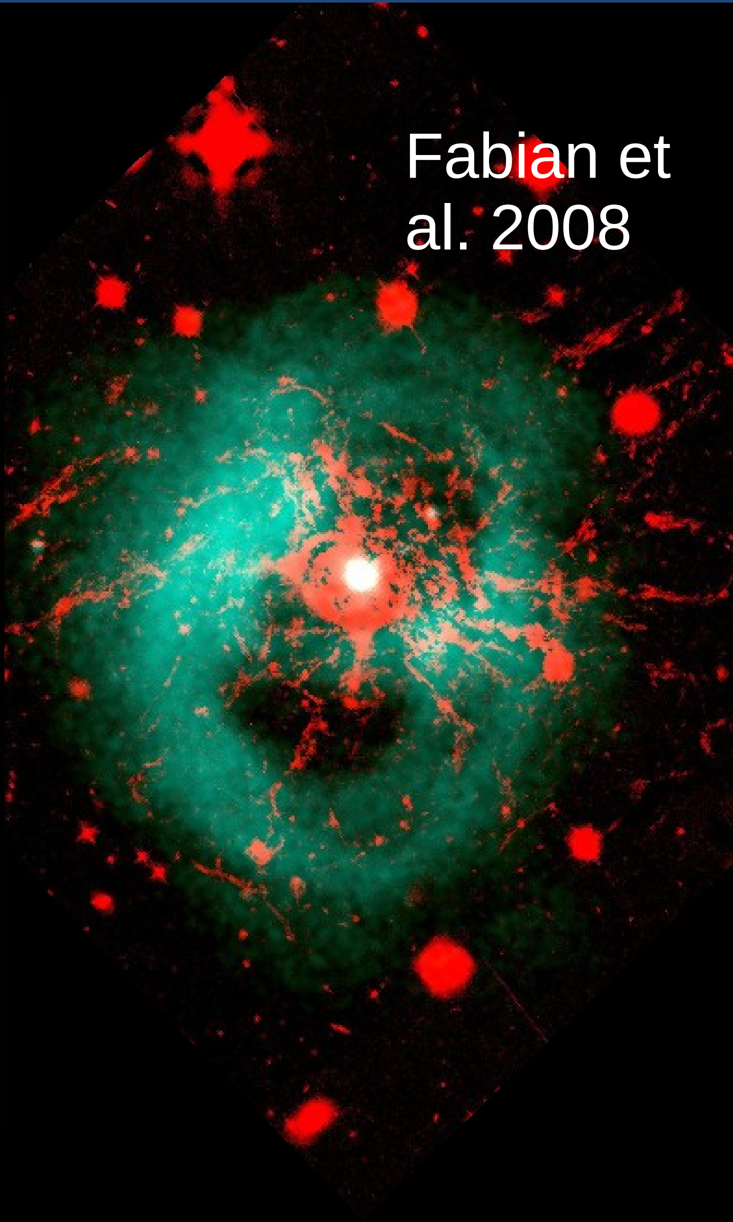
Falceta-Goncalves, de Gouveia Dal Pino, Gallagher, Lazarian ApJ lett. 2010a

MHD simulation of Perseus: SN turbulence + AGN jet in center

Turbulent kinetic energy not efficiently converted into heat: **additional heating** required to suppress cooling flow → **AGN**



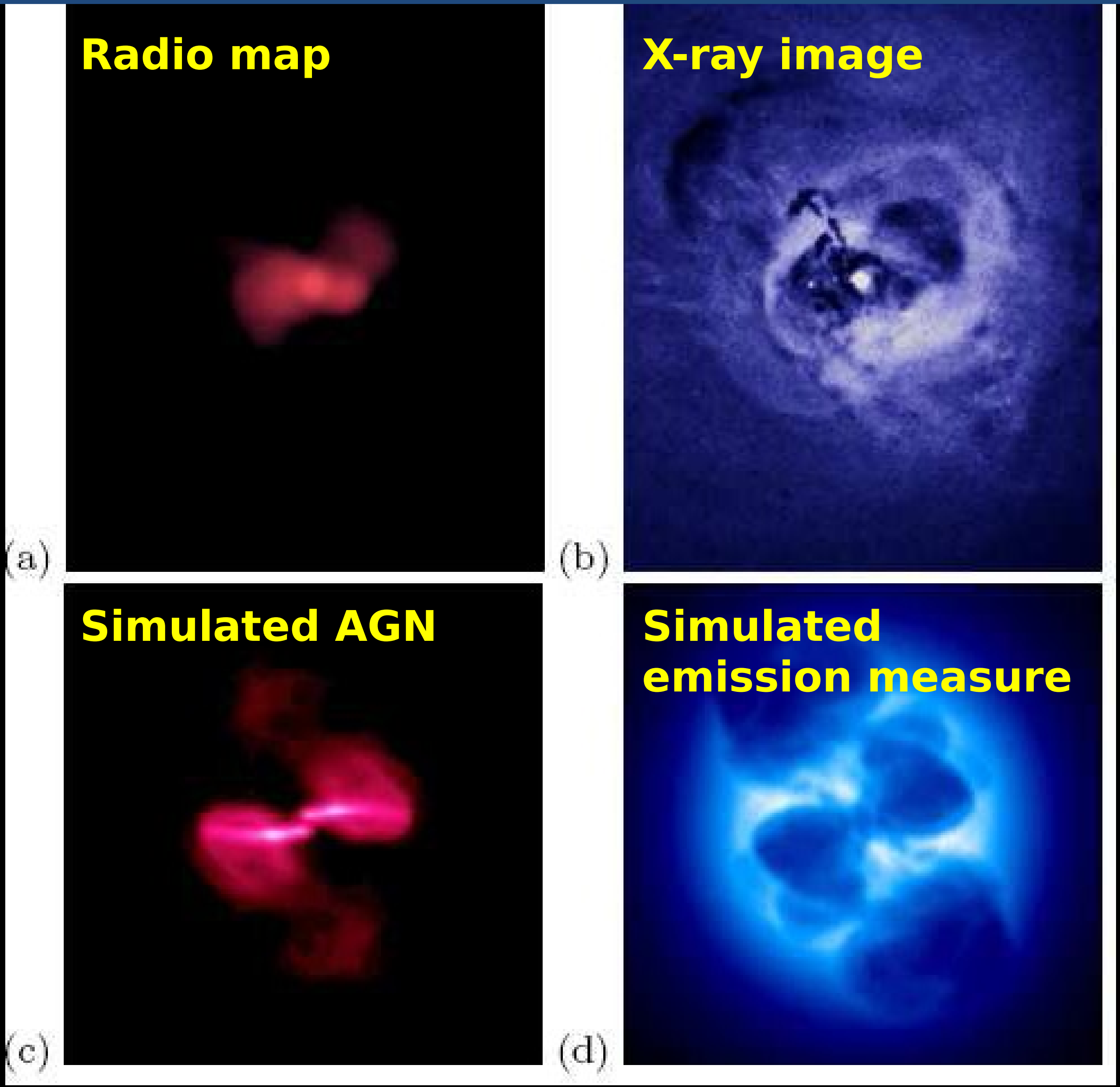
$L_{AGN} = 10^{42}$ erg/s
$v_{jet} = 10^{4}$ km/s



Fabian et al. 2008

Falceta-Goncalves et al., ApJ. Lett, 2010a

MHD simulation of Perseus: with precessing AGN jet in center



Precessing jet can also isotropize injected AGN energy distribution

Falceta-Goncalves et al., ApJ. Lett, 2010b

Summary

Turbulence effect on star formation @ pc:

- MF removal from collapsing clouds and cores, which is usually attributed to AD, can be successfully accomplished with turbulent reconnection only.
- Turbulence can play a role in the removal of B-flux in **different phases of star-formation** and make molecular clouds – **subcritical** → **supercritical**.

Further study:

Investigation of the relative role of the AD versus reconnection diffusion.

Summary

Star formation feedback @ kpc:

- **Star formation/SN turbulence** explains isotropic distribution of filaments, magnetic fields an weak shocks and ripples around central galaxy in Perseus cluster.

- **Cluster of galaxies: AGN** represents the **main source of heating** against **cooling flows**, but **MHD turbulence** (a dominating source of momentum) may be necessary to help to **isotropize** heating distribution.