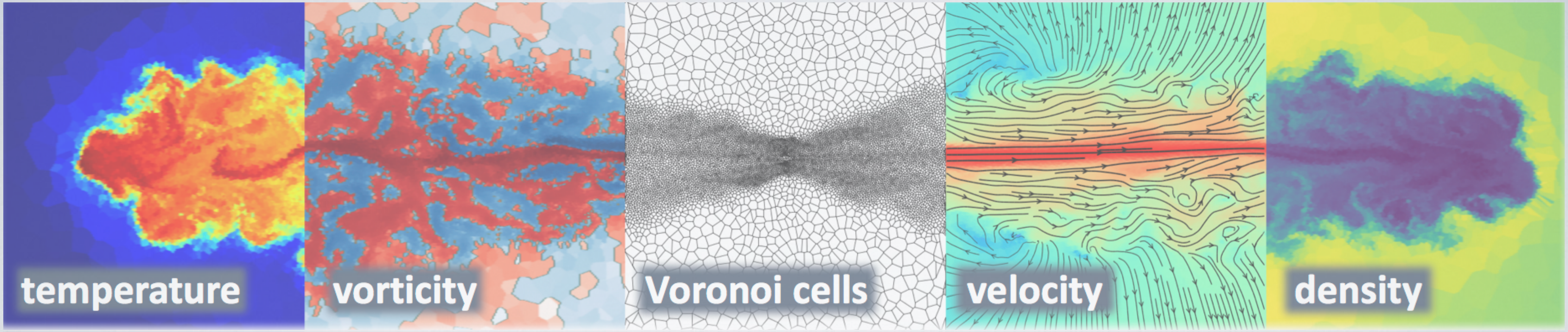

SIMULATION OF AGN JET FEEDBACK (ON A MOVING MESH)

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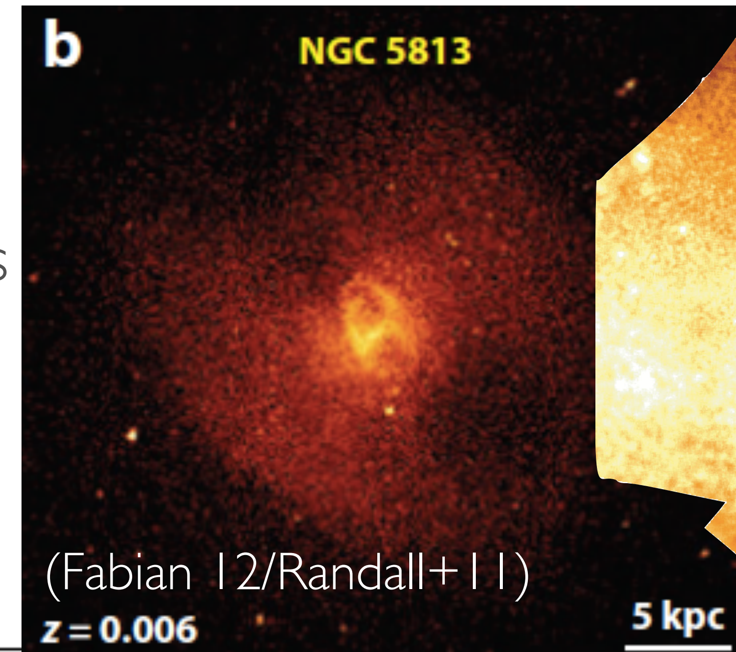
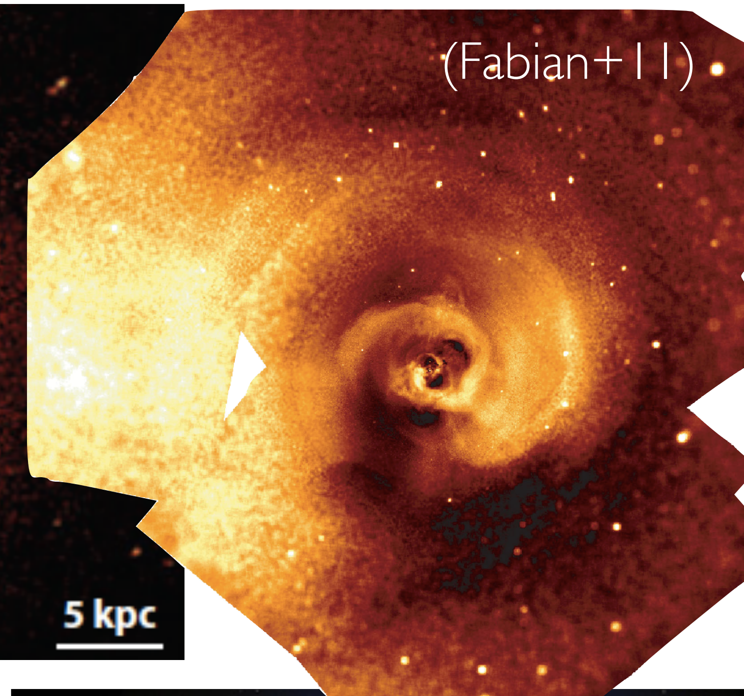
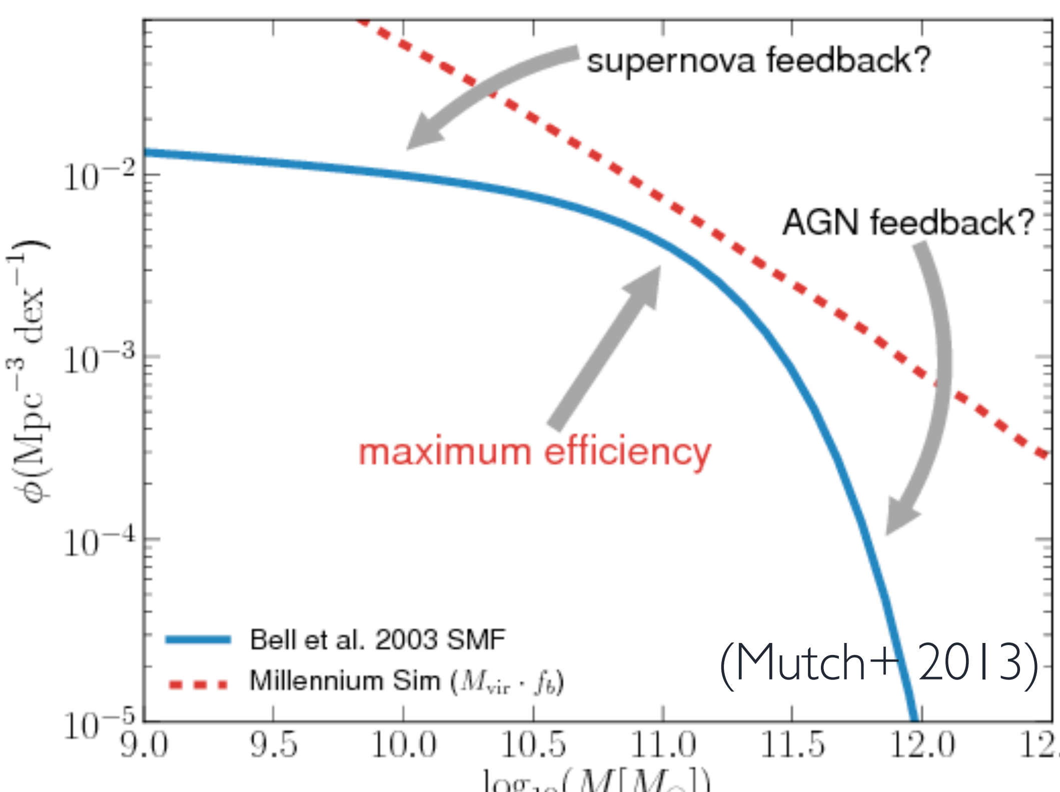
DiRAC
erc

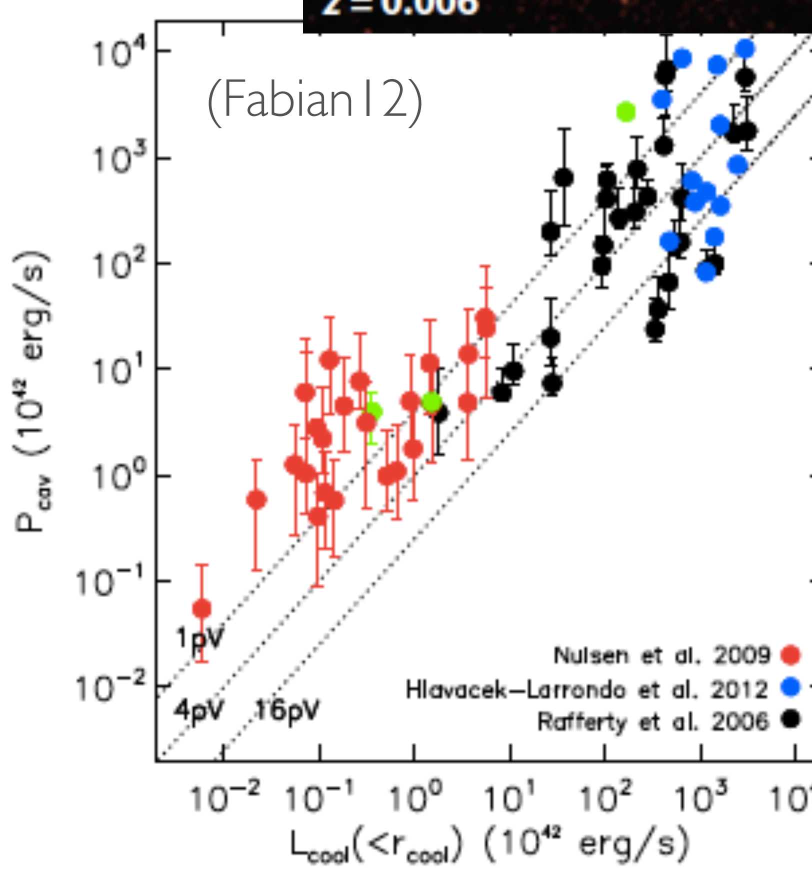
FEEDBACK IN GALAXY GROUPS &CLUSTERS

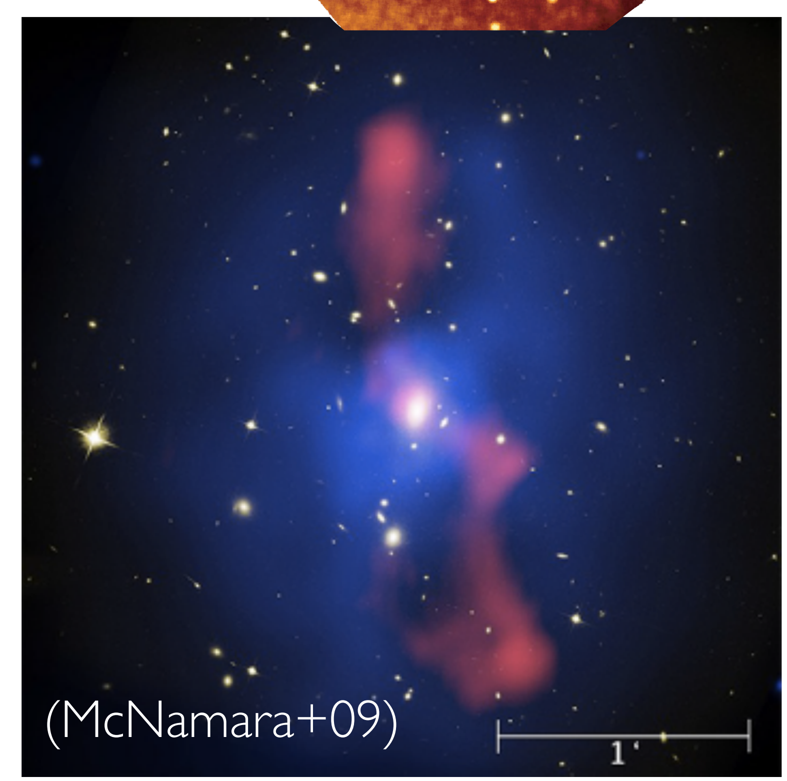
- AGN feedback is important in galaxy evolution
- Groups & clusters contain X-ray cavities and jets
- Regulate heating and cooling in ICM
- How is the jet energy communicated?











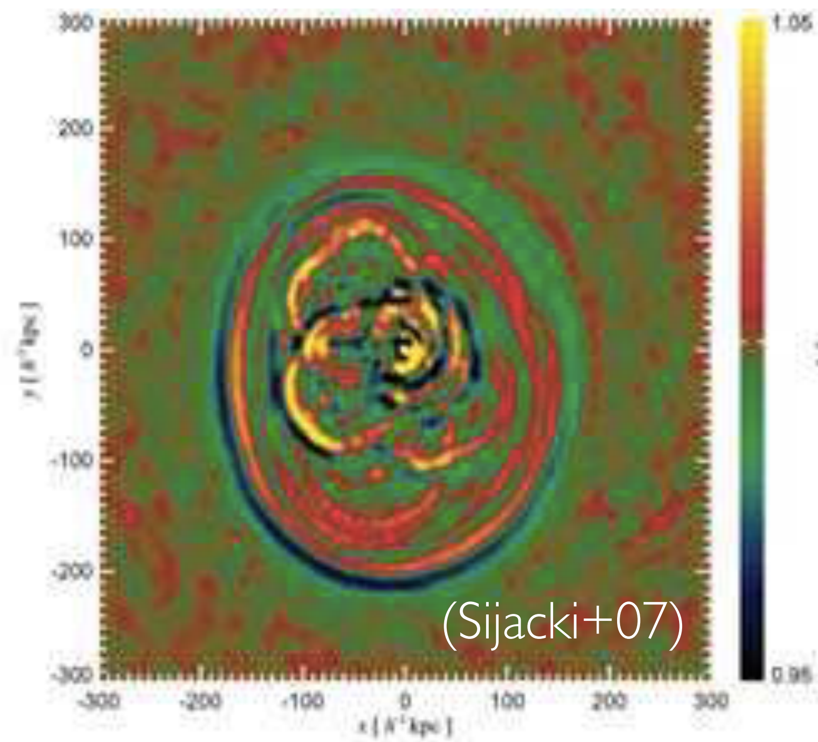
SIMULATION OF AGN JET FEEDBACK

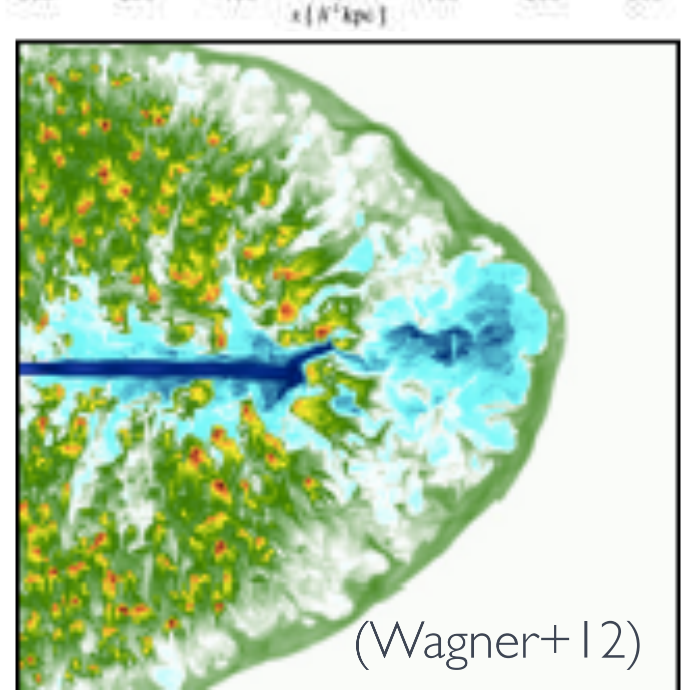
- Mimic effect of jets - hot bubbles
  (e.g. Quilis+01, Sijacki+07)

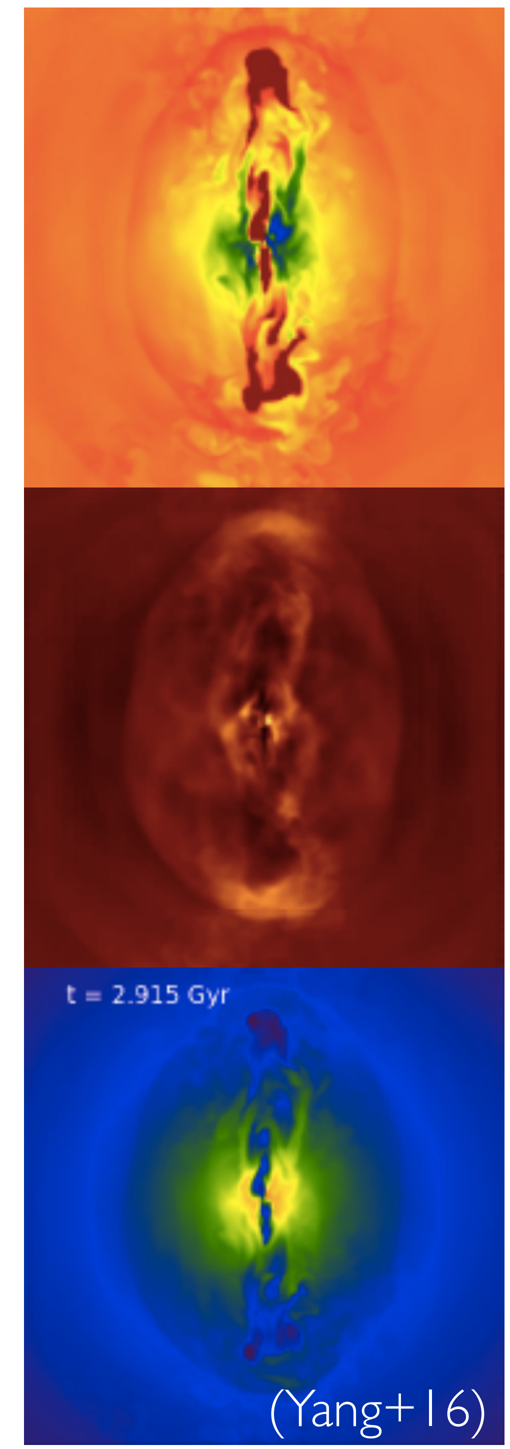
- Momentum + Thermal
  (e.g. Omma+ 04, Cattaneo+07, Li+ 14)

- Pure Kinetic
  (e.g. Dubois+10, Gaspari+11, Yang+16)

- Clumpy ISM
  (e.g. Wagner+12)

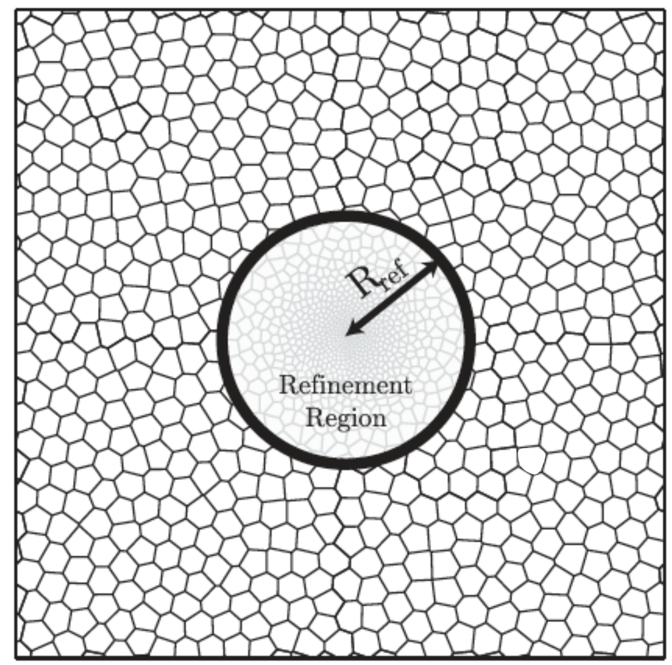


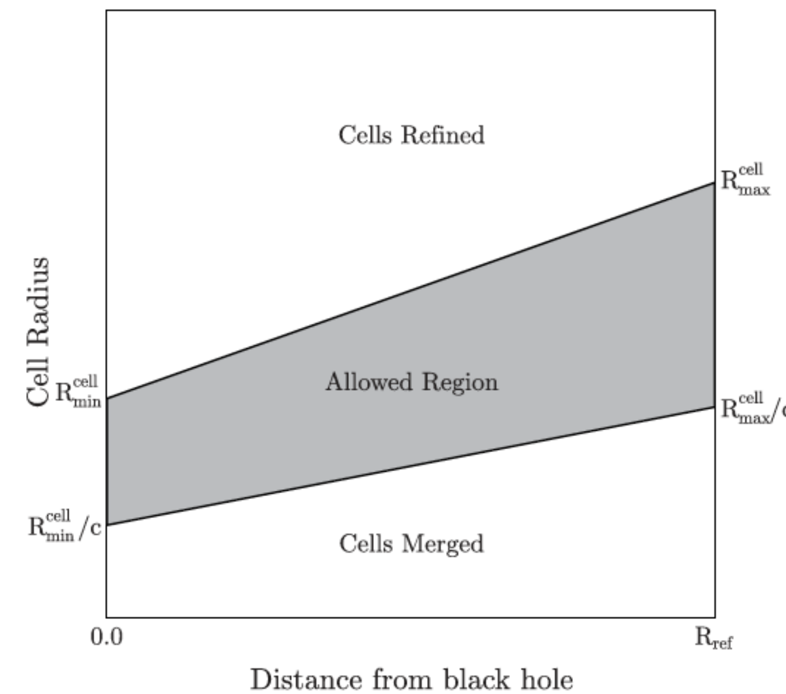


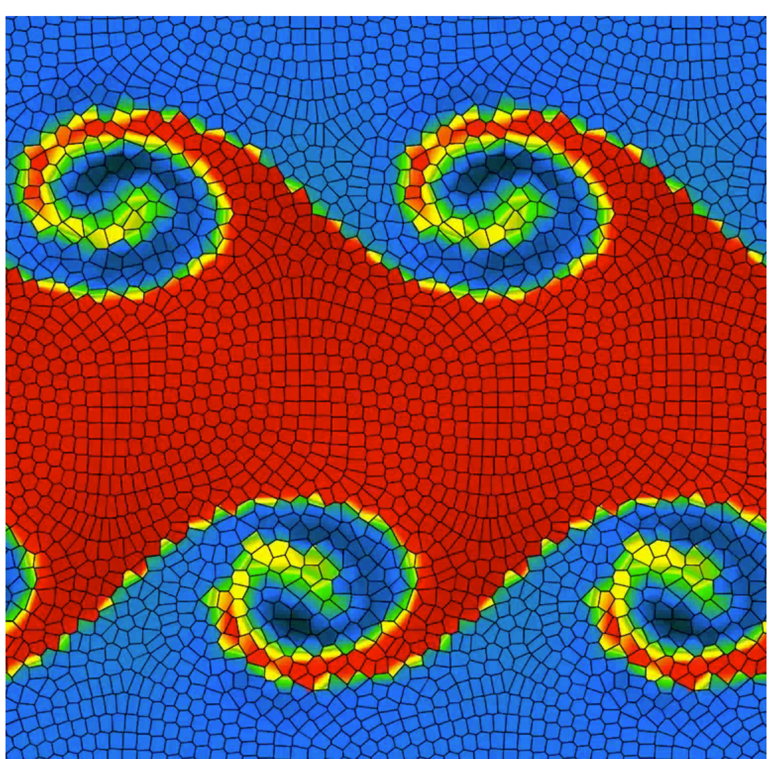


AREPO
& SUPER-LAGRANGIAN REFINEMENT

- Springel 2010
- Moving mesh - Voronoi cells
- Lagrangian/Eulerian hybrid



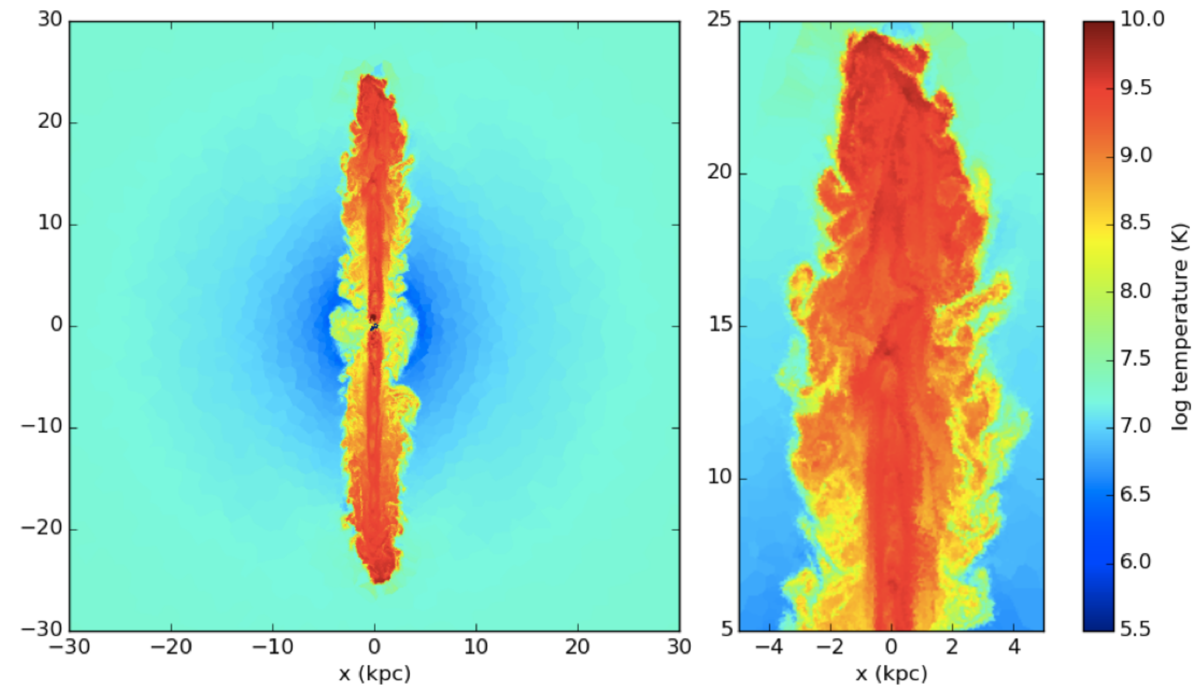


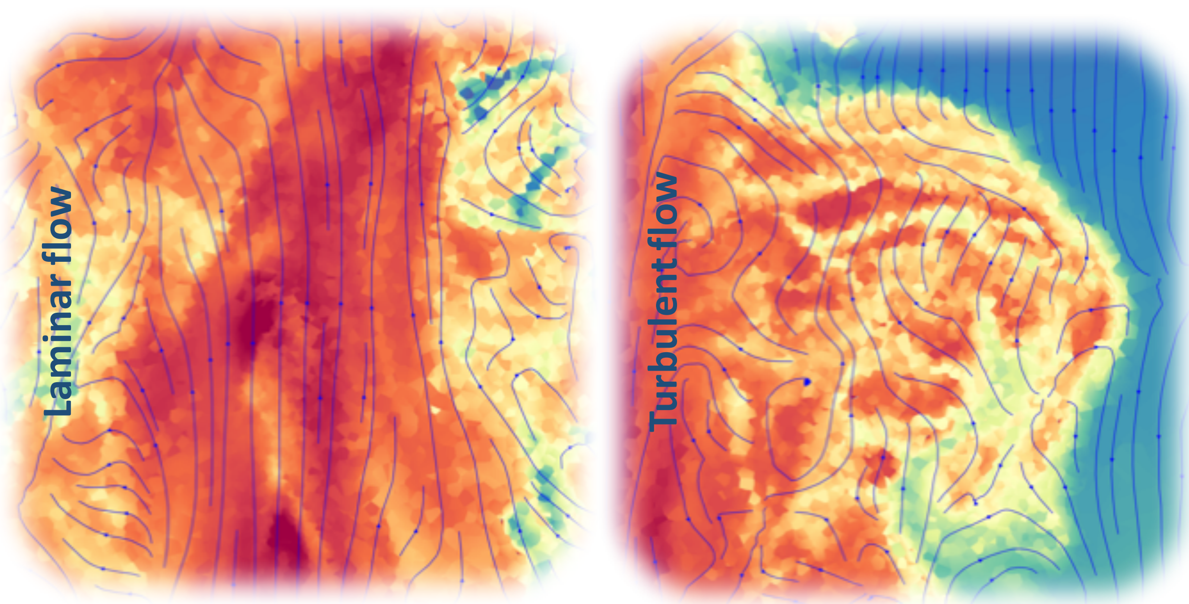


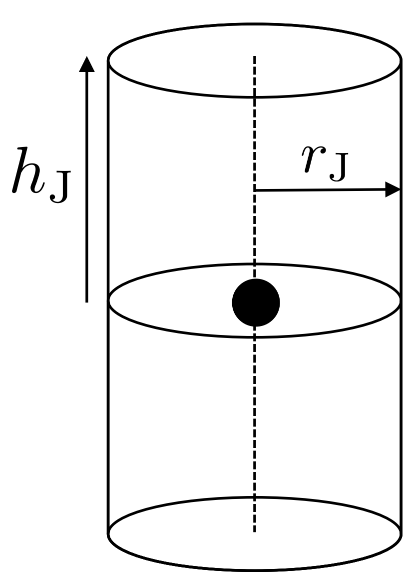
- Curtis & Sijacki 2015
- Improve resolution around BH
- Better capture gas dynamics to improve accretion estimates

JET INJECTION

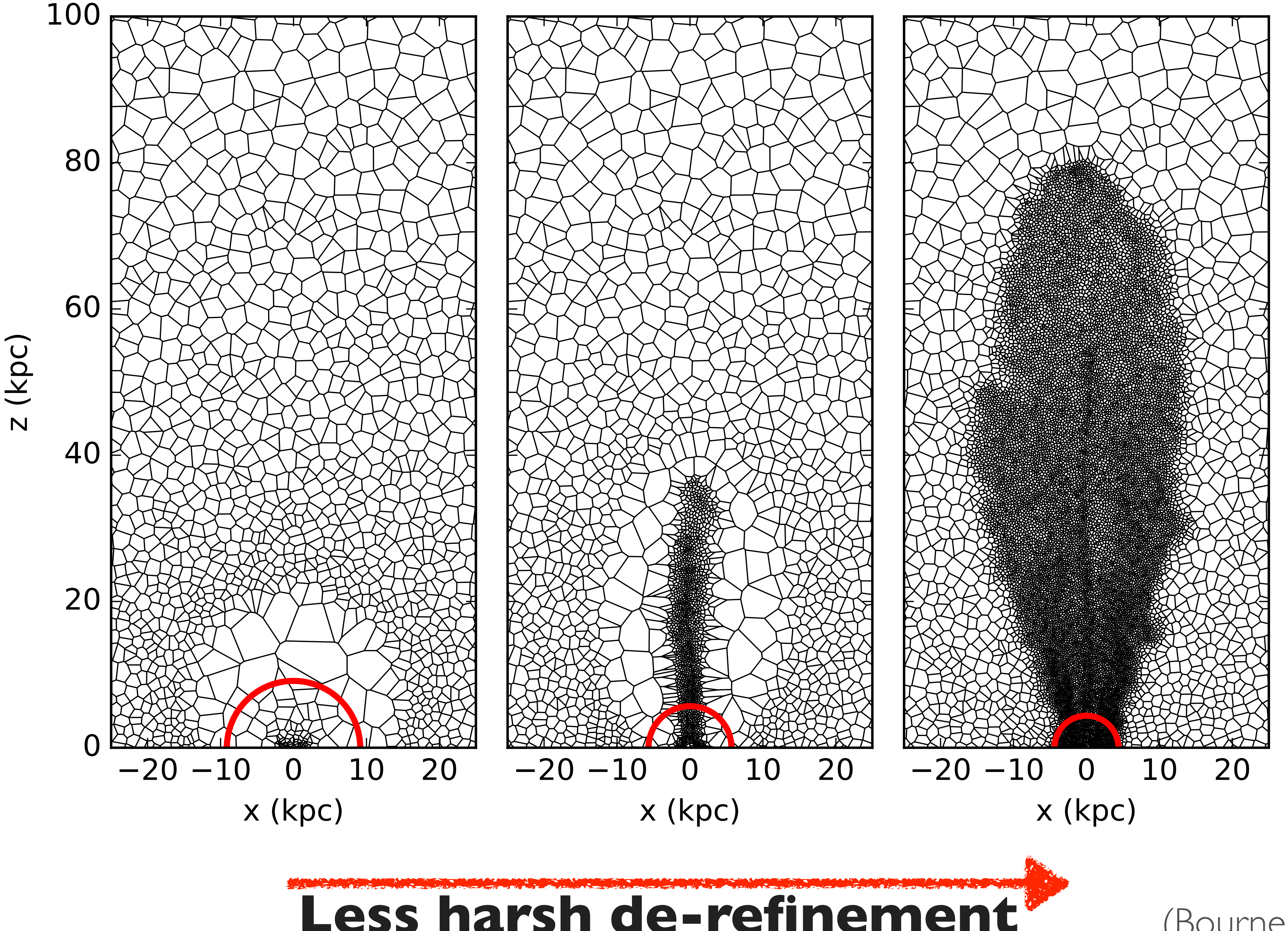
- Inject jet into a cylinder of fixed mass
- Add mass, momentum and energy to cells
- Jet remains well resolved even in generally low resolution simulation







DE-REFINEMENT



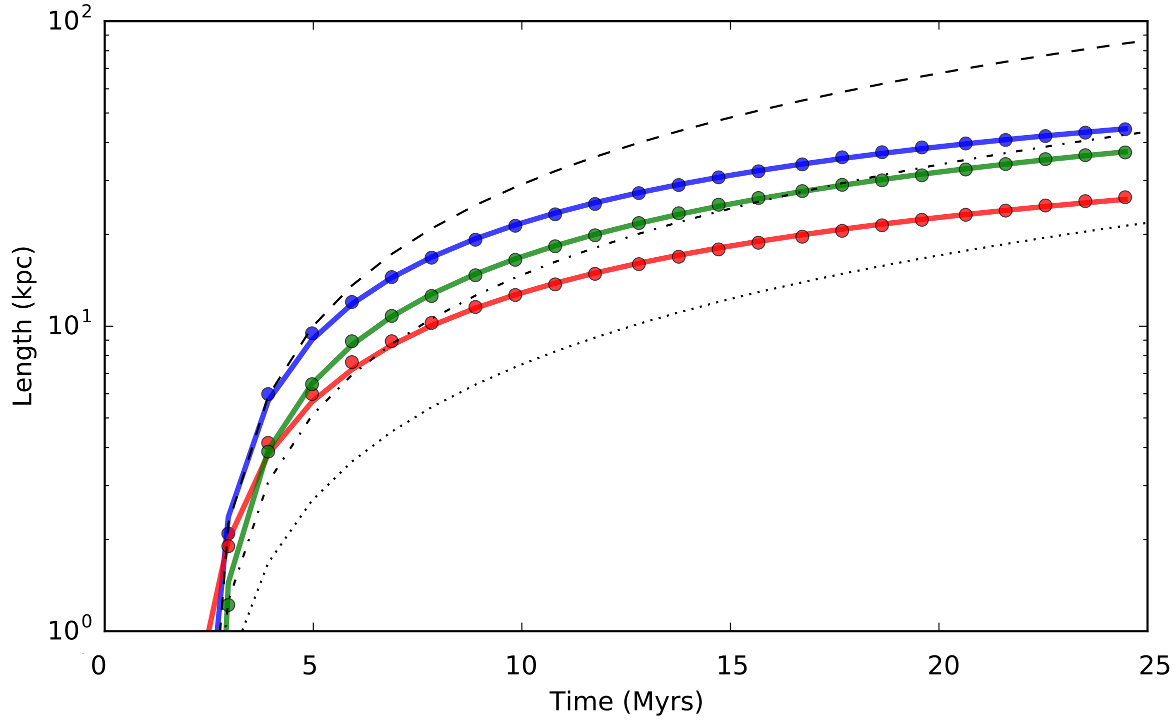
smallest cell ~ 7 pc

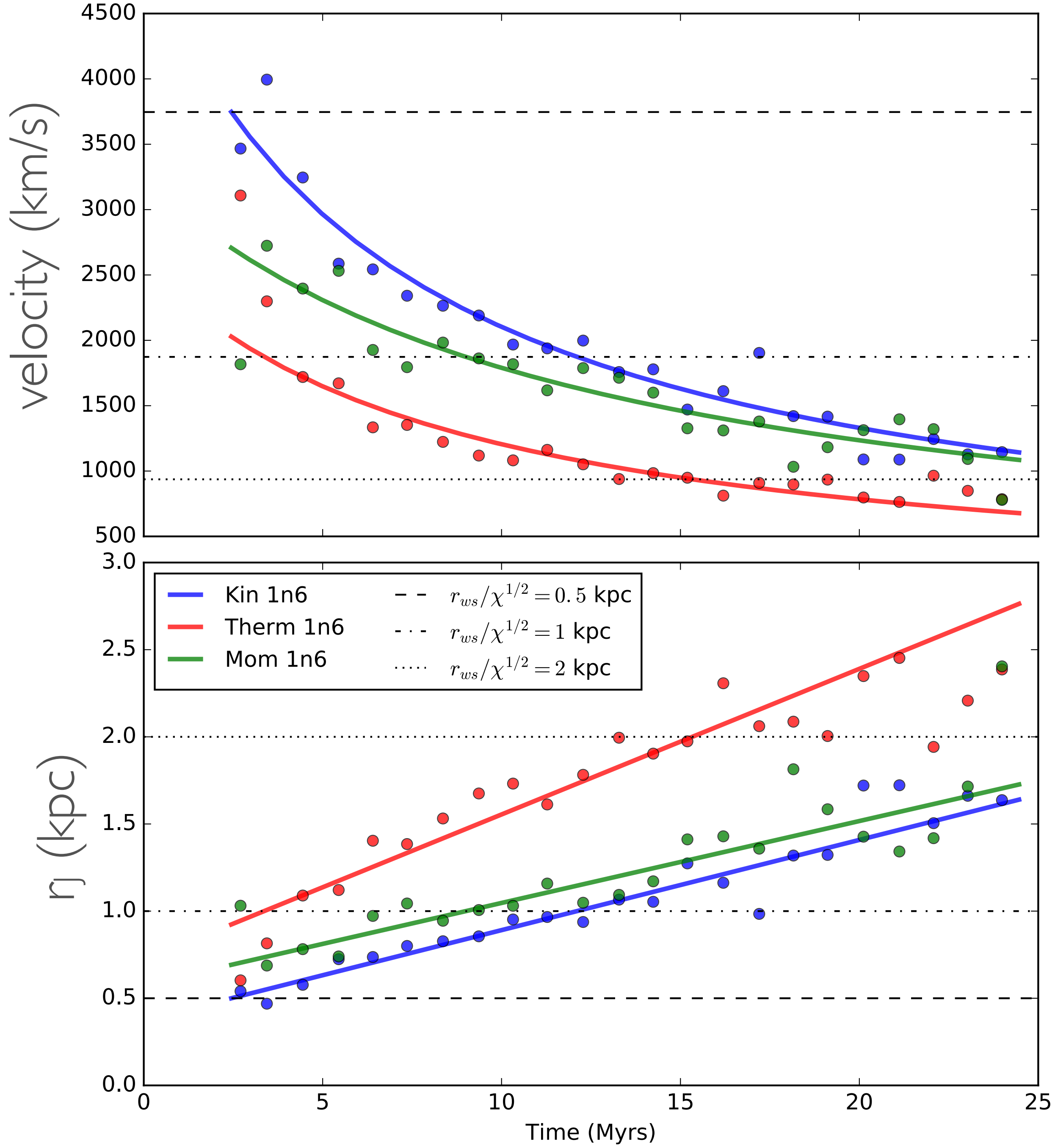
R_{vir} ~750 kpc

Sim Domain ~17.5 Mpc

(Bourne & Sijacki, in prep)

JET EVOLUTION - ANALYTICAL COMPARISON

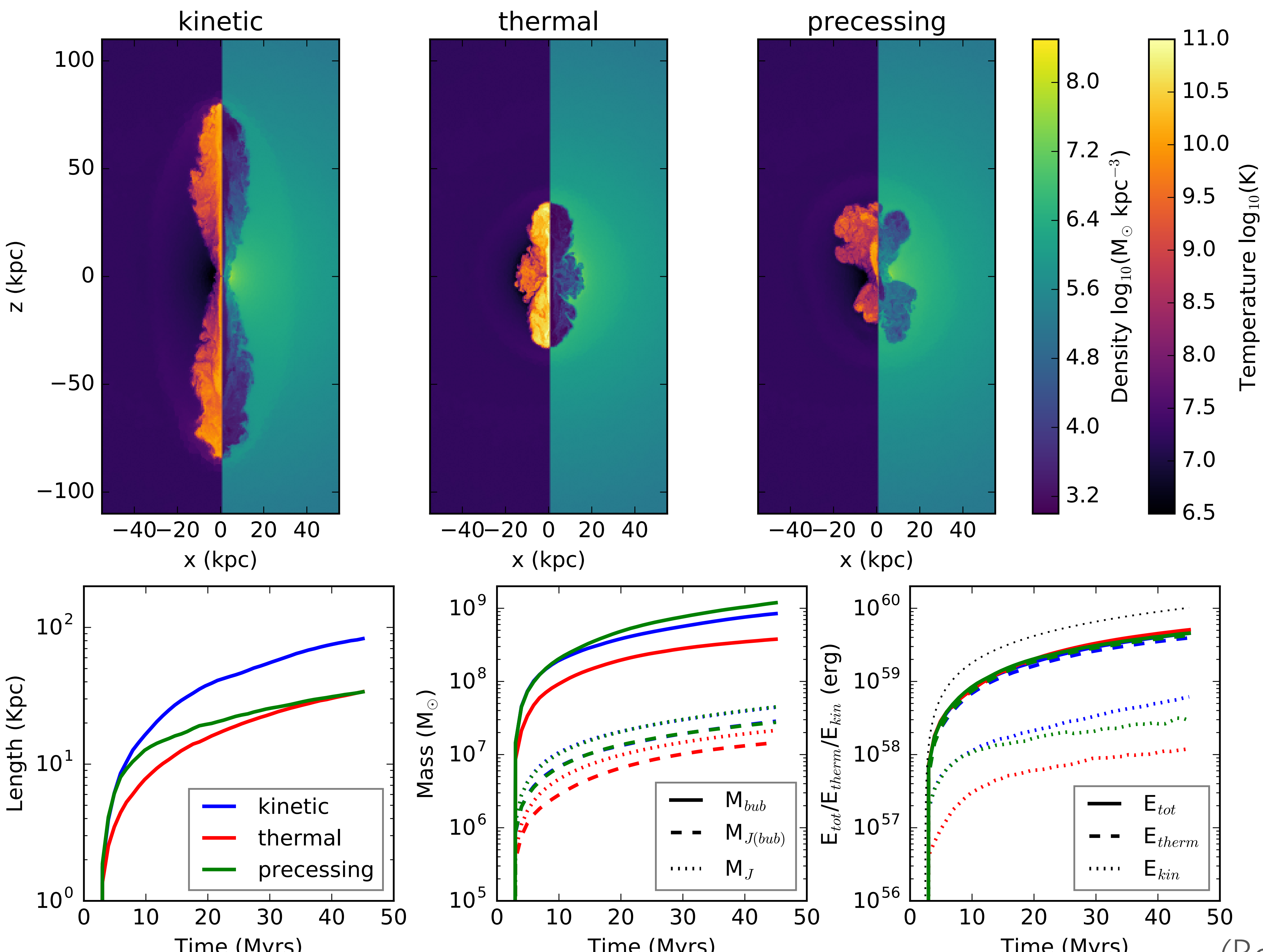




- Idealised simulations - constant density background, no cooling
- Ram-pressure force determines length evolution (e.g. Begelman&Ciofi 89)
- Working area of jet broadens (e.g. Krause+01, 03)
- Bow shock velocity slows

(Bourne & Sijacki, in prep)

ENERGY INJECTION METHODS



$$M_{\rm tot} = 10^{14} M_\odot$$

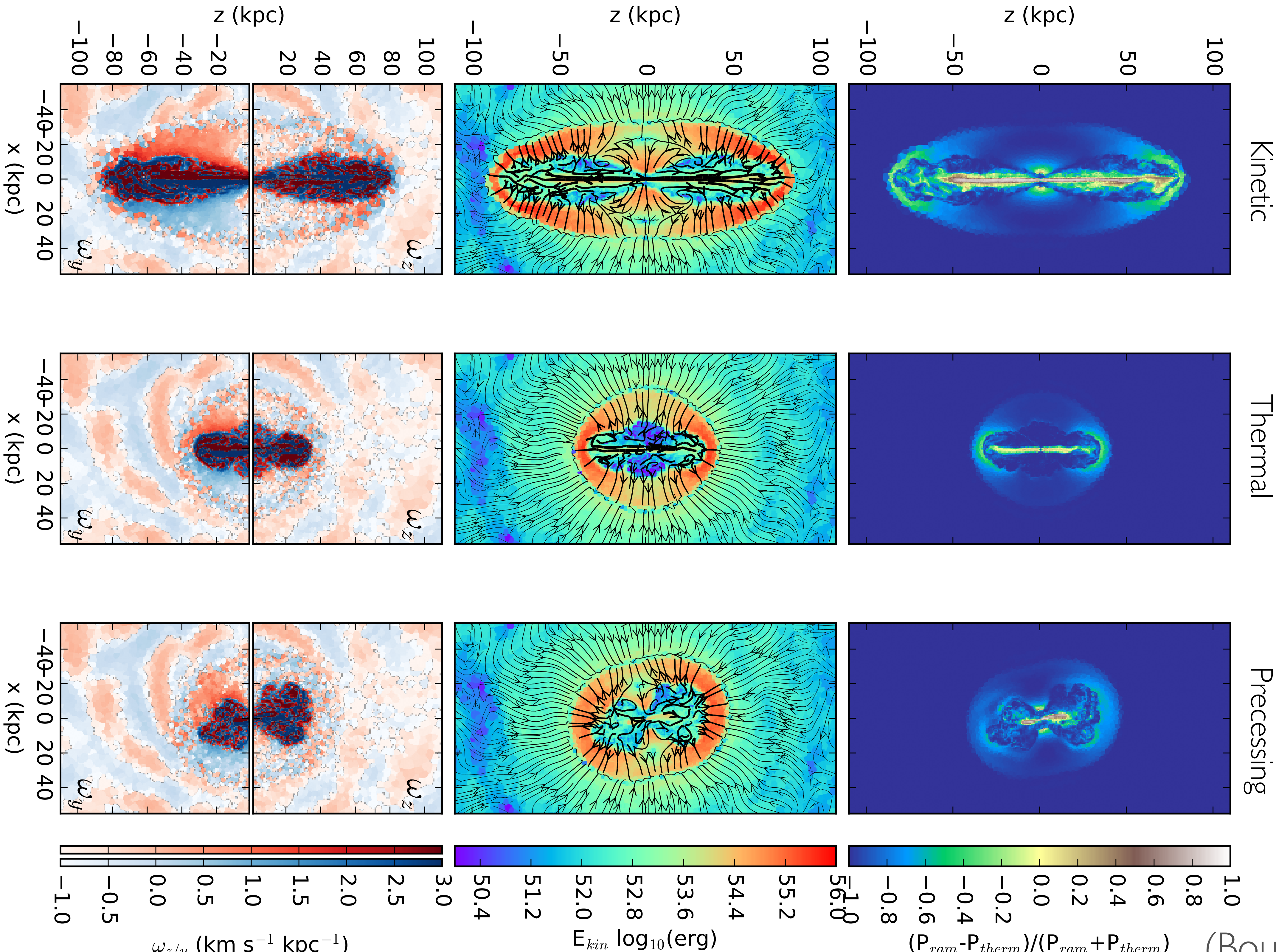
$$M_{\rm BH,0} = 10^{9} M_\odot$$

$$\dot{m}_{\rm Jet} = 0.01 \dot{M}_{Edd}$$

$E_{kin} < 0.15\ E_{bub}$

(Bourne & Sijacki, in prep)

JET INFLATION AND GAS FLOWS



Jet/bow shock - P_{ram}

cavity - P_{therm}

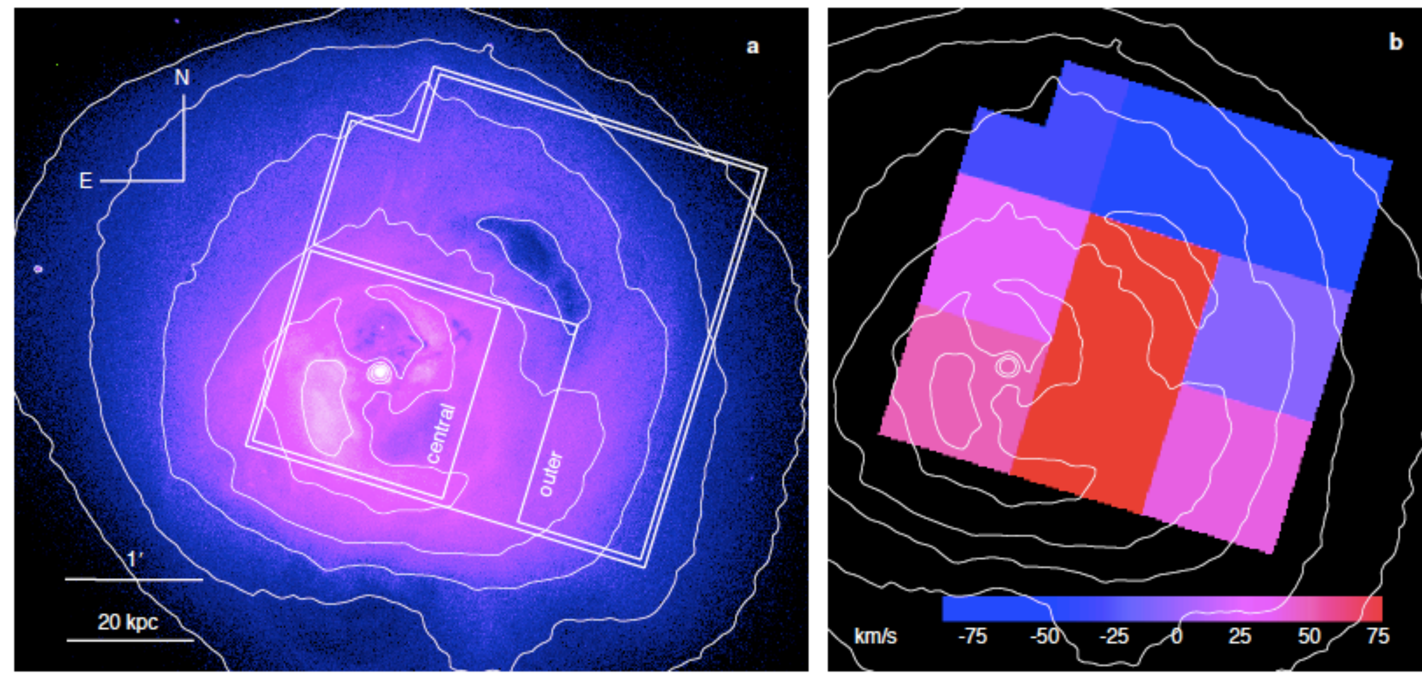
High E_k shell

High vorticity confined to bubble material

(Bourne & Sijacki, in prep)

TURBULENCE IN GROUPS & CLUSTERS

(Hitomi Collaboration 16)

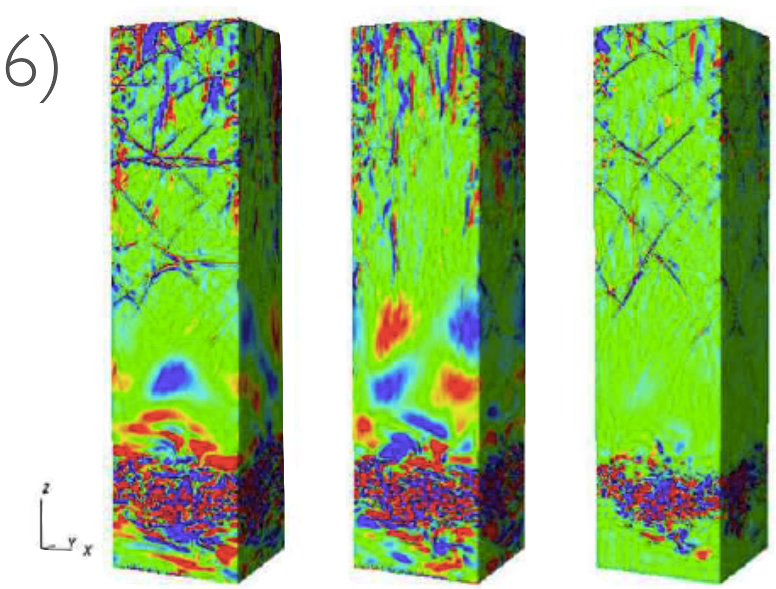


- Observations - ICM contains a *small* turbulent component
  (e.g., Sanders+11,12,13, Pinto+15, Hitomi+16)

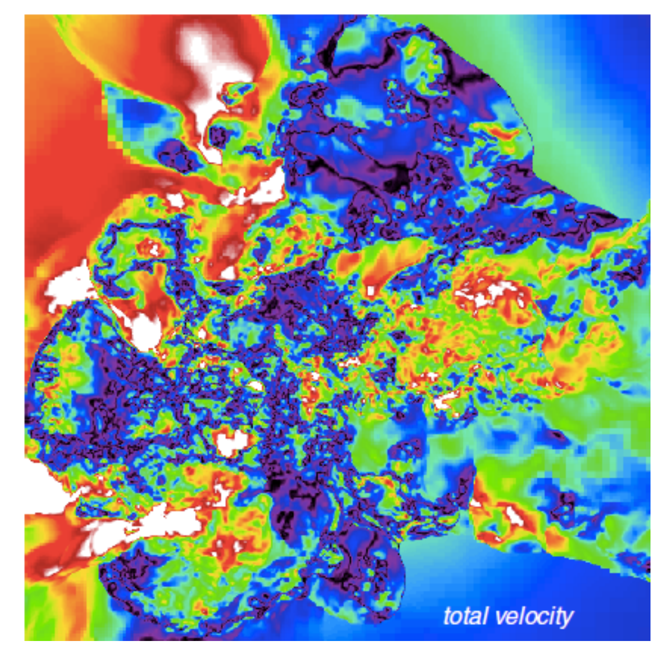
- Structure formation & Galaxy motions?
  (e.g. Dolag+ 05, Gu+13, Vazza+12,16)

- Sloshing?
  (e.g. Vazza+12, ZuHone+13)

- Feedback?
  (e.g. <u>Brüggen</u>+05, <u>Zhuravleva</u>+14)
  (although - Hillel&Soker 16, Reynolds+15 Yang&Reynolds16)

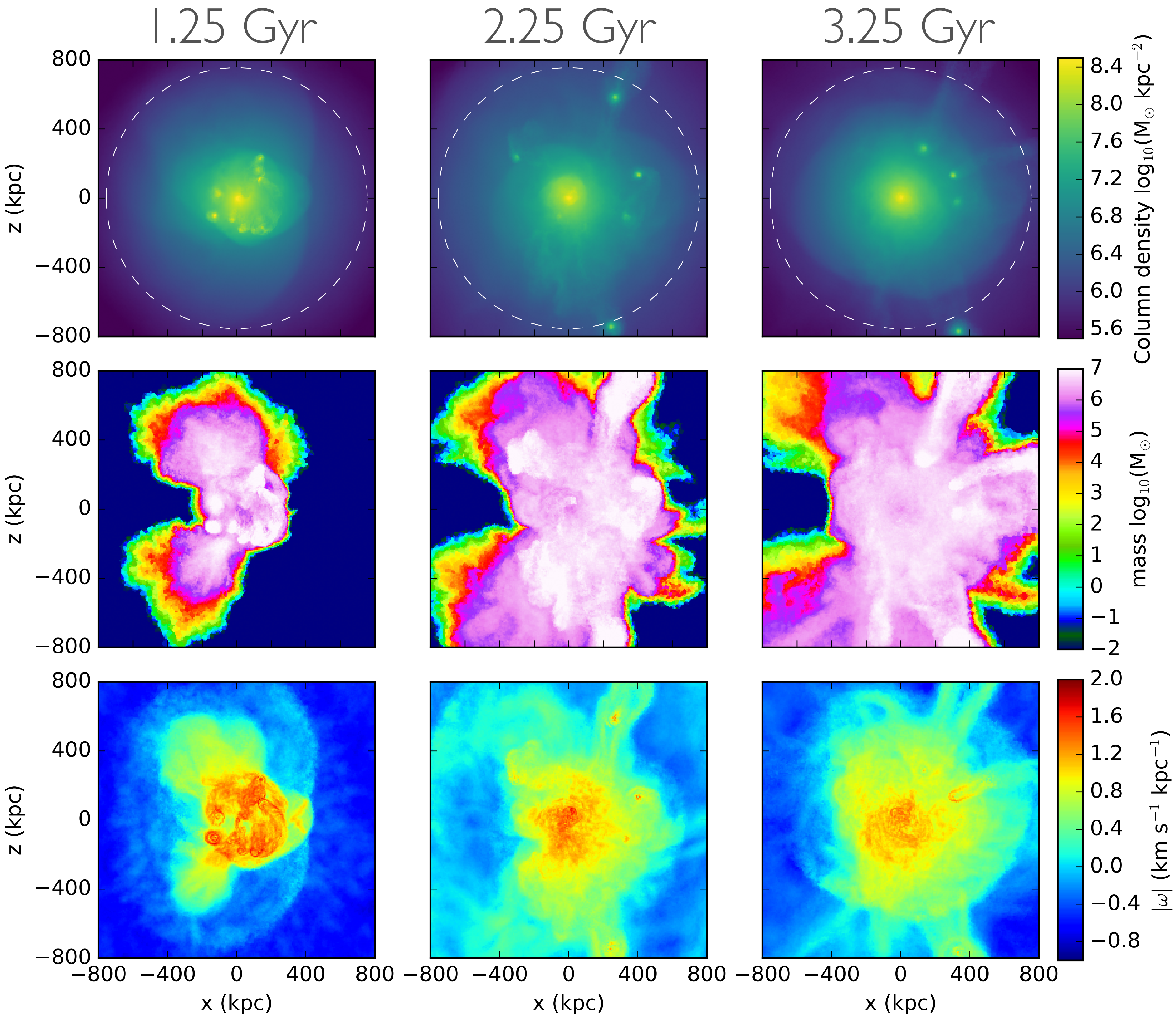


(Reynolds + 16)



(Vazza + 16)

SUB-STRUCTURE MOTIONS



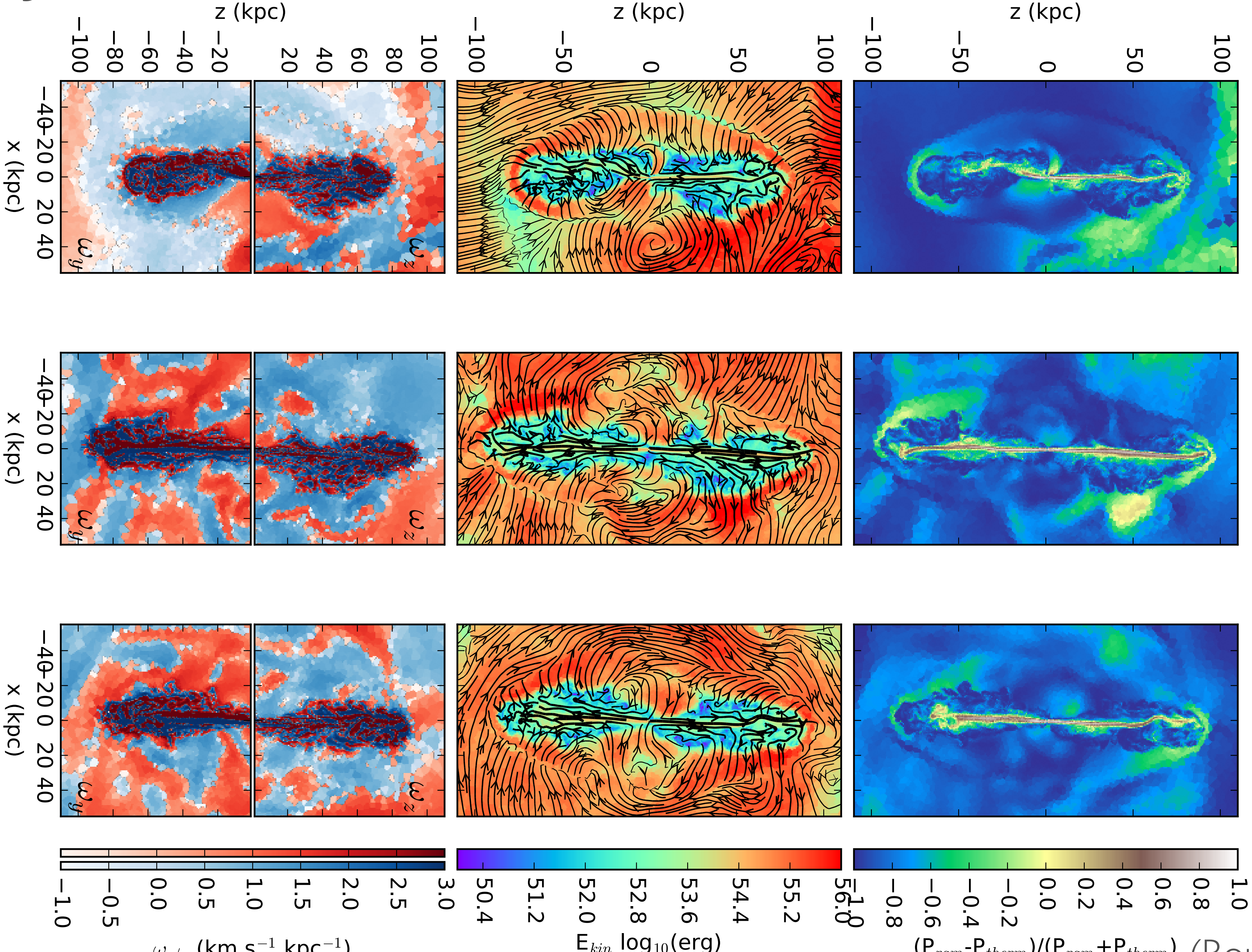
Add sub halos by hand

Stir ICM

Produce turbulence and vorticity

(Bourne & Sijacki, in prep)

JET INFLATION AND GAS FLOWS

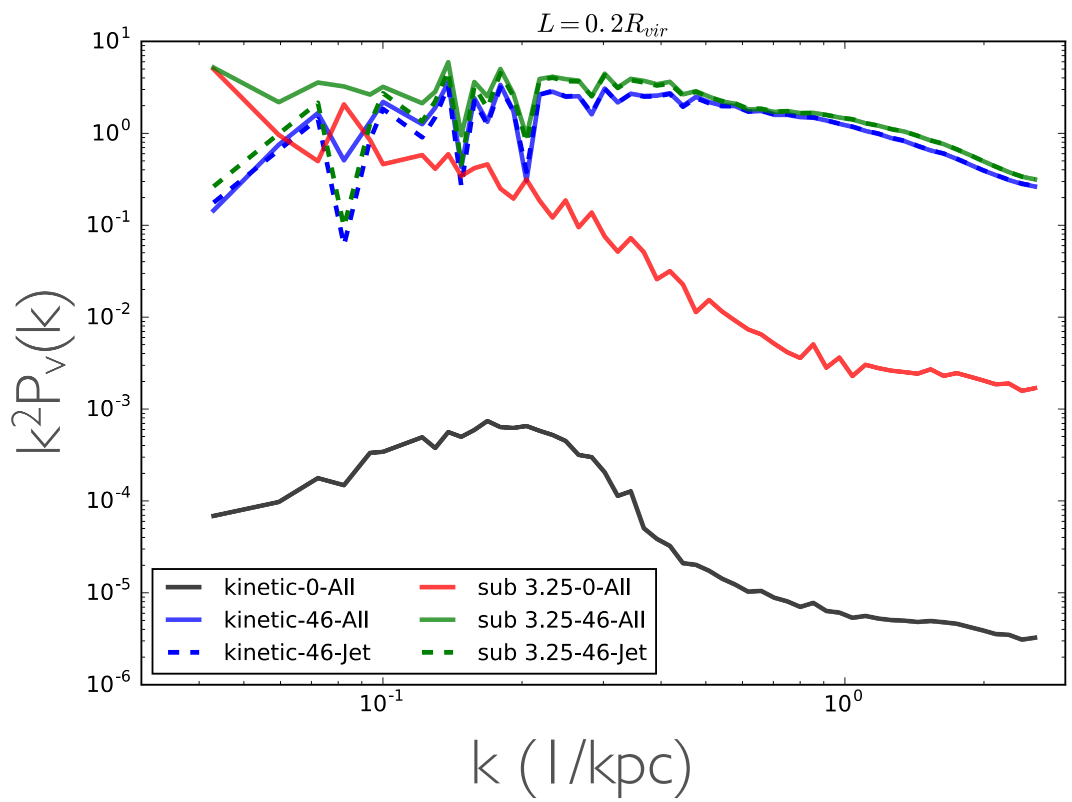


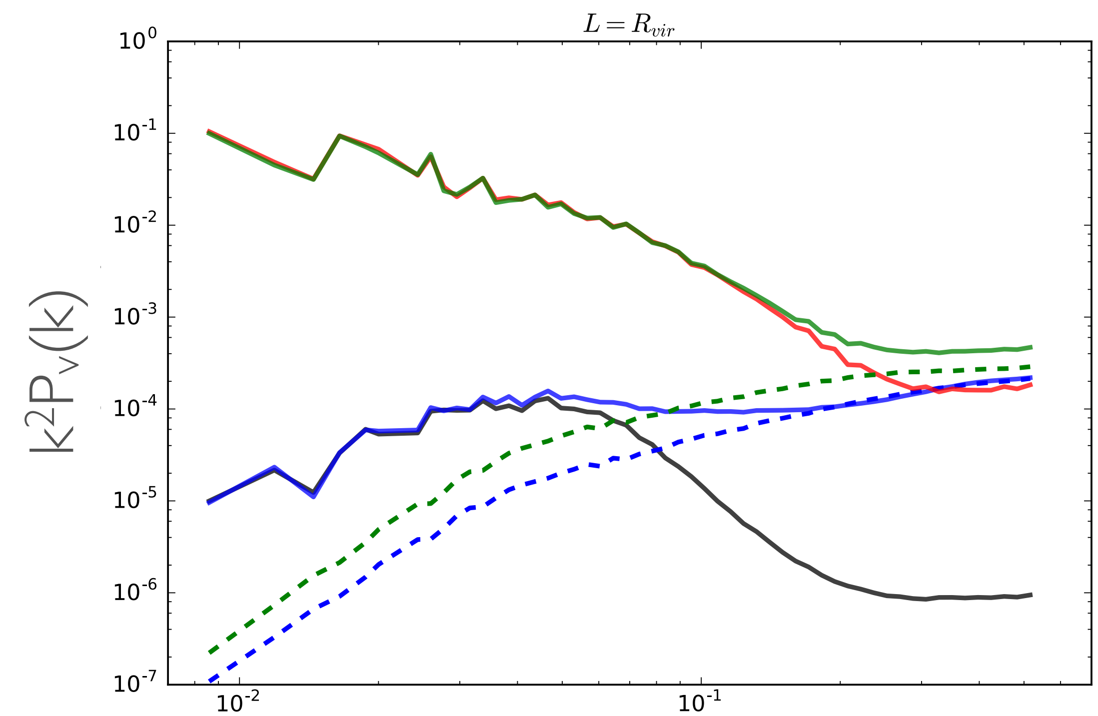
Gas flows disrupt jet cocoon

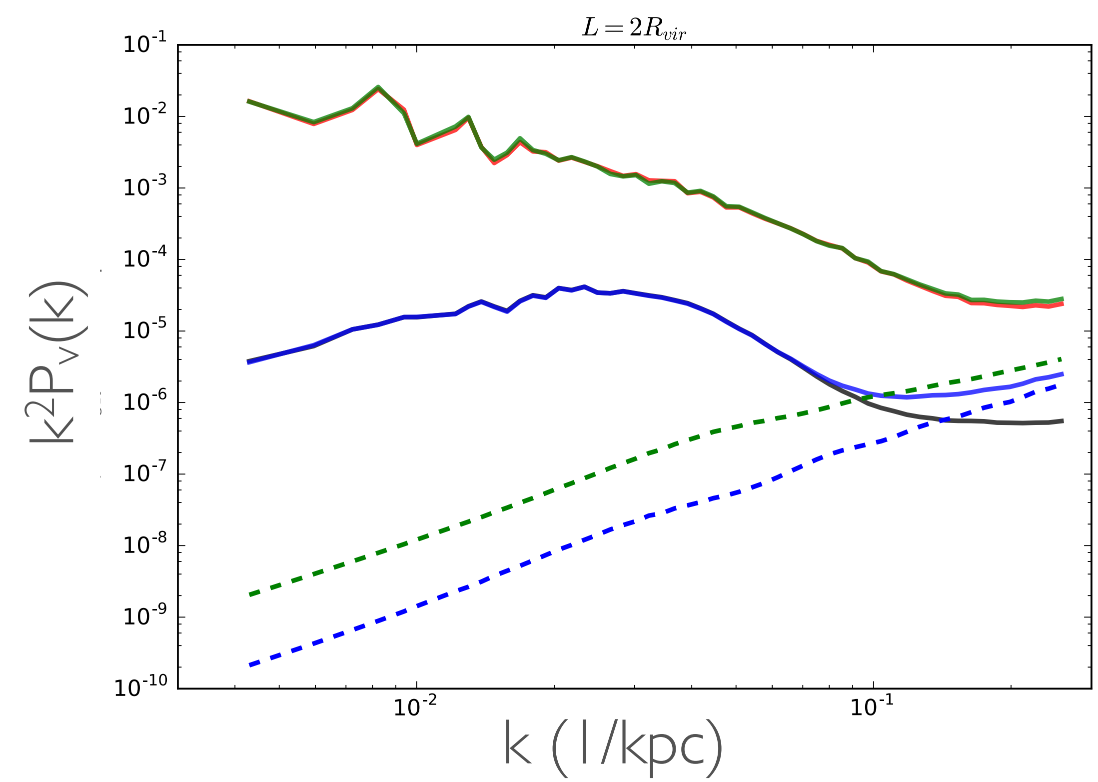
Greater pre-existing vorticity

(Bourne & Sijacki, in prep)

DRIVING TURBULENCE







- Jet dominates power on small scales
- Has little impact on larger scales - confined to cocoon material
- sub-structure produces turbulent cascade on larger scales

(Bourne & Sijacki, in prep)

SUMMARY

- Implemented a new jet feedback scheme into AREPO - refinement allows the jet to be produced with high resolution on small scales and span a large dynamic range
- Tested various jet injection techniques to investigate impact on jet and halo evolution
- Investigated impact of sub-structure on driving turbulence in the ICM and subsequent evolution of the jet - pre-existing gas motions impact cocoon structure and aid mixing
- Jets dominate the velocity power spectrum on small scales - jet driven turbulence and vorticity is confined to the jet cocoon, in particular the jet material - accounts for a small fraction of the total injected energy