# QUENCHING THE X-RAY SPECTRUM OF HOT HALOS WITH AGN OUTFLOWS AND TURBULENCE


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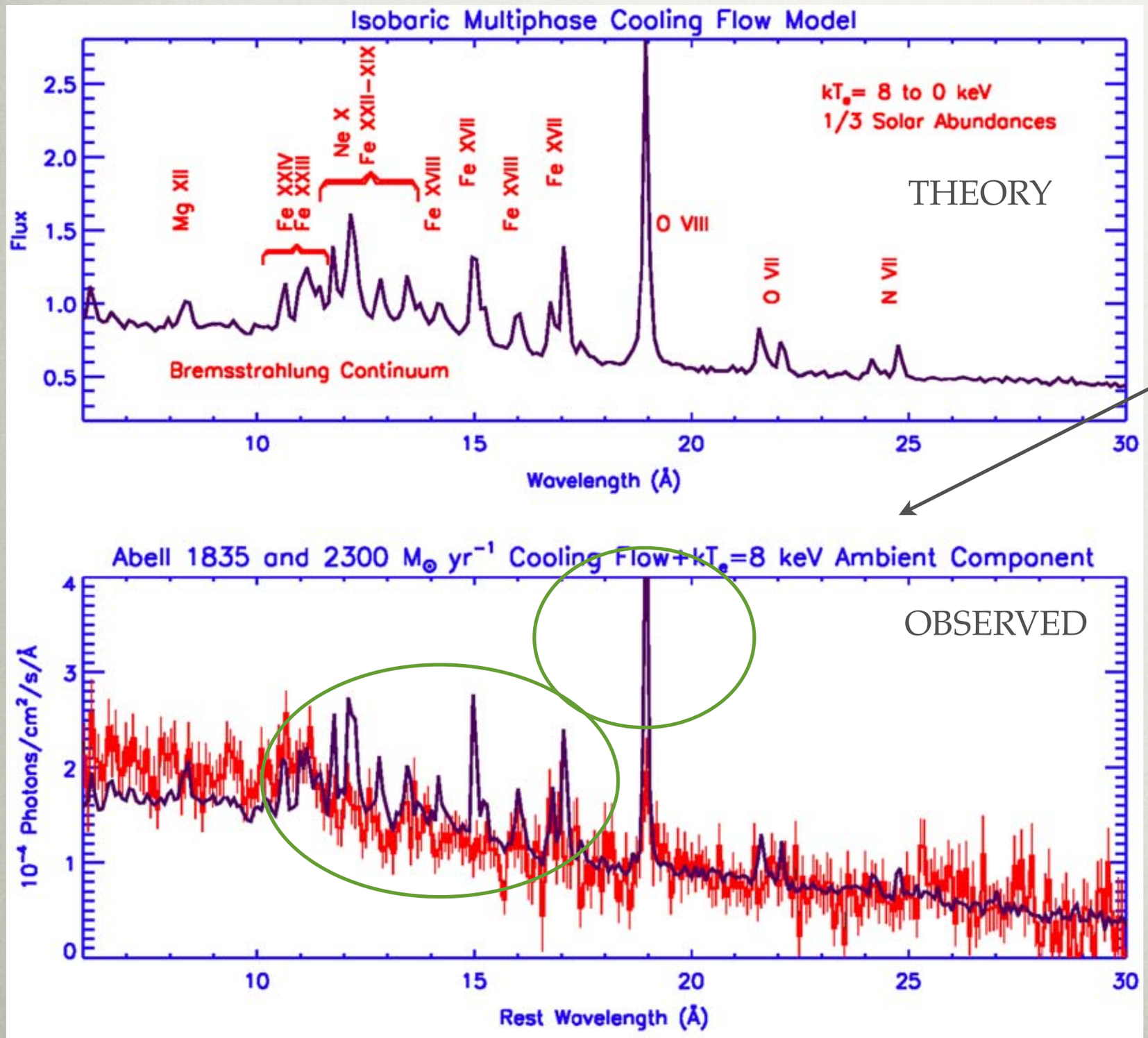
# Quenching Cooling Flows




$$\dot{M}_{\rm obs} = 1 - 10\%\ \dot{M}_{\rm CF}$$

deficit of major lines in the X-ray/UV spectrum

$$T \lesssim 10^7\ {\rm K}$$

*XMM-RGS* energy spectra
(e.g., Peterson+2001, 2003, 2006)

mass sink problem vs
soft X-ray problem

AGN **heating** mechanism?

AGN **feeding** mechanism?

# CCA: CHAOTIC COLD ACCRETION (RAINING ON SMBHs)

**cloud condensation out of the hot halo via nonlinear thermal instability**

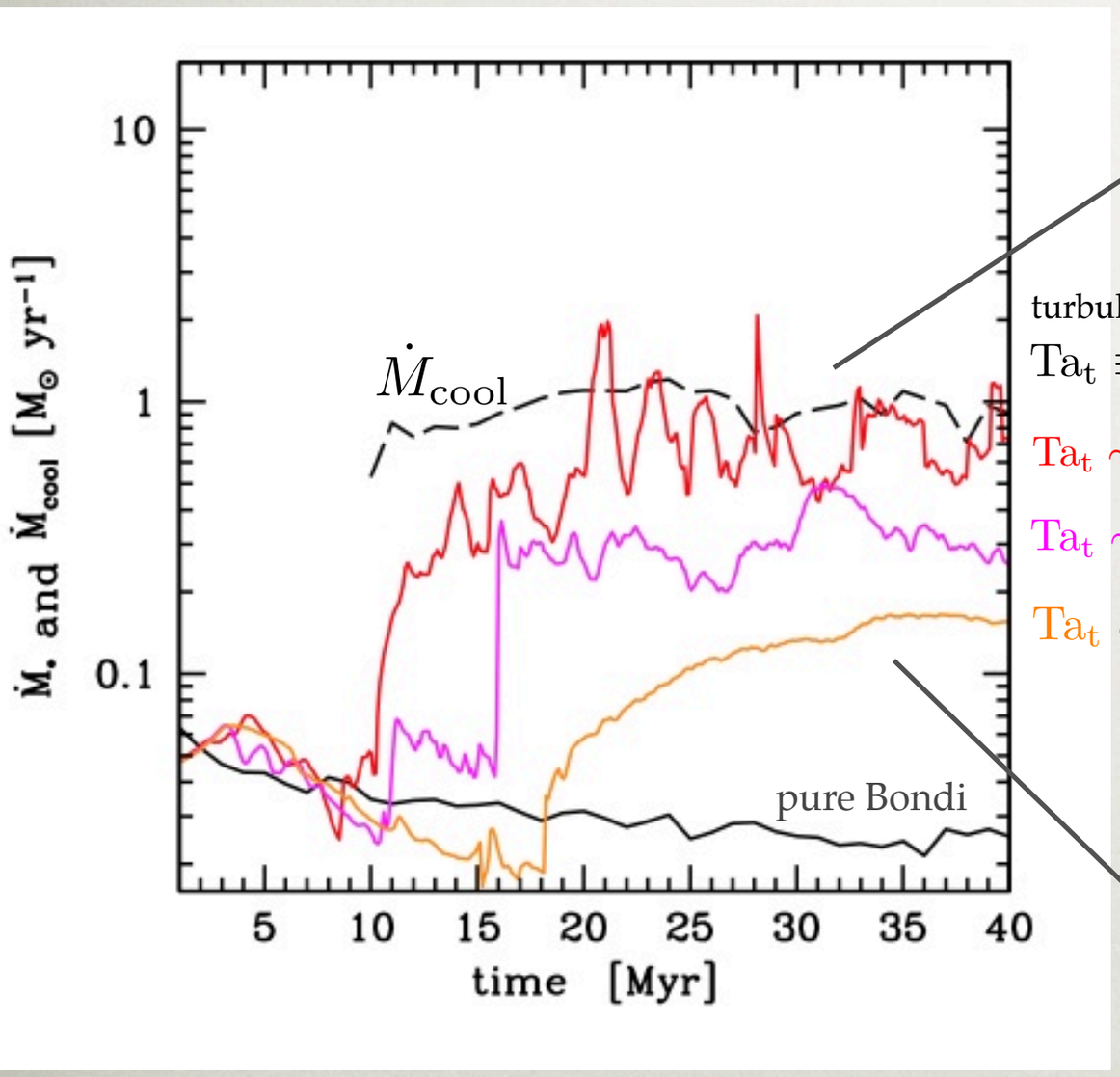
Gaspari et al. 2013-2015

$$\dot{M}_{\rm BH} \sim 100\,\dot{M}_{\rm Bondi} \sim \dot{M}_{\rm cool}$$

$$\sigma_v \simeq 150\ {\rm km/s}$$

**CCA dominates**

$${\rm Ta_t} < 1$$




turbulent Taylor number

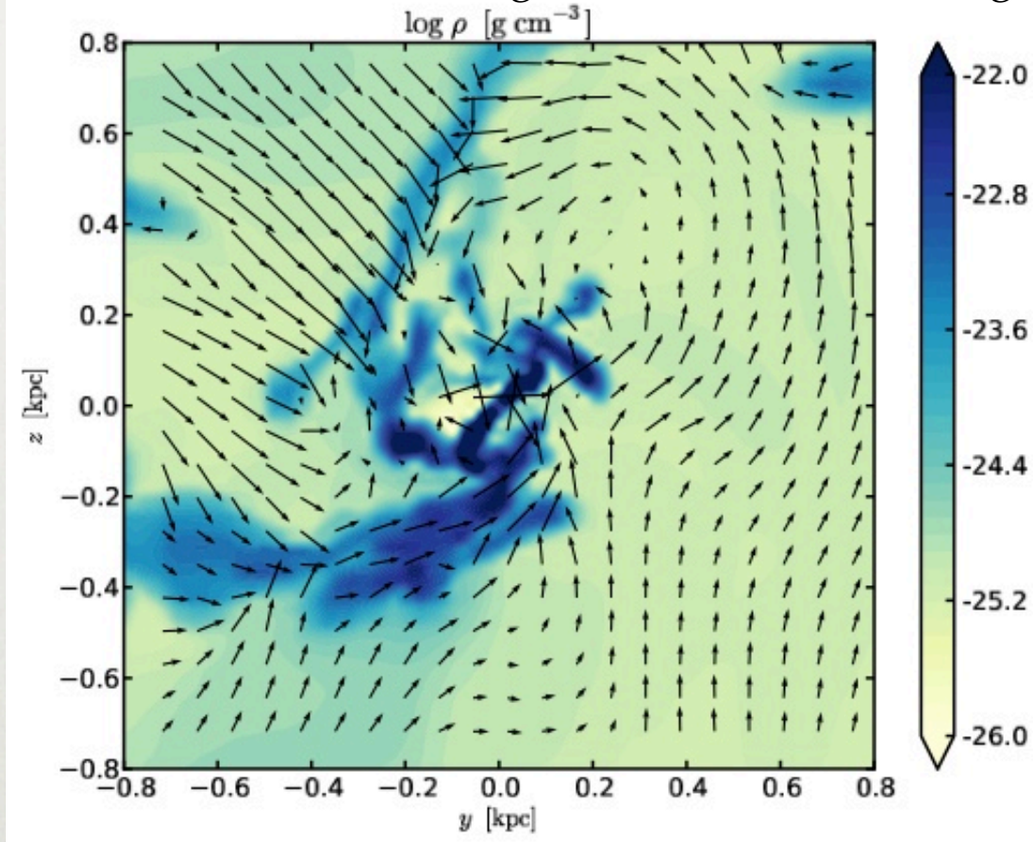
$${\rm Ta_t} \equiv v_{\rm rot}/\sigma_v$$

$${\rm Ta_t} \sim 0.75$$

$${\rm Ta_t} \sim 1.5$$

$${\rm Ta_t} \sim 3$$

inelastic collisions => angular momentum mixing



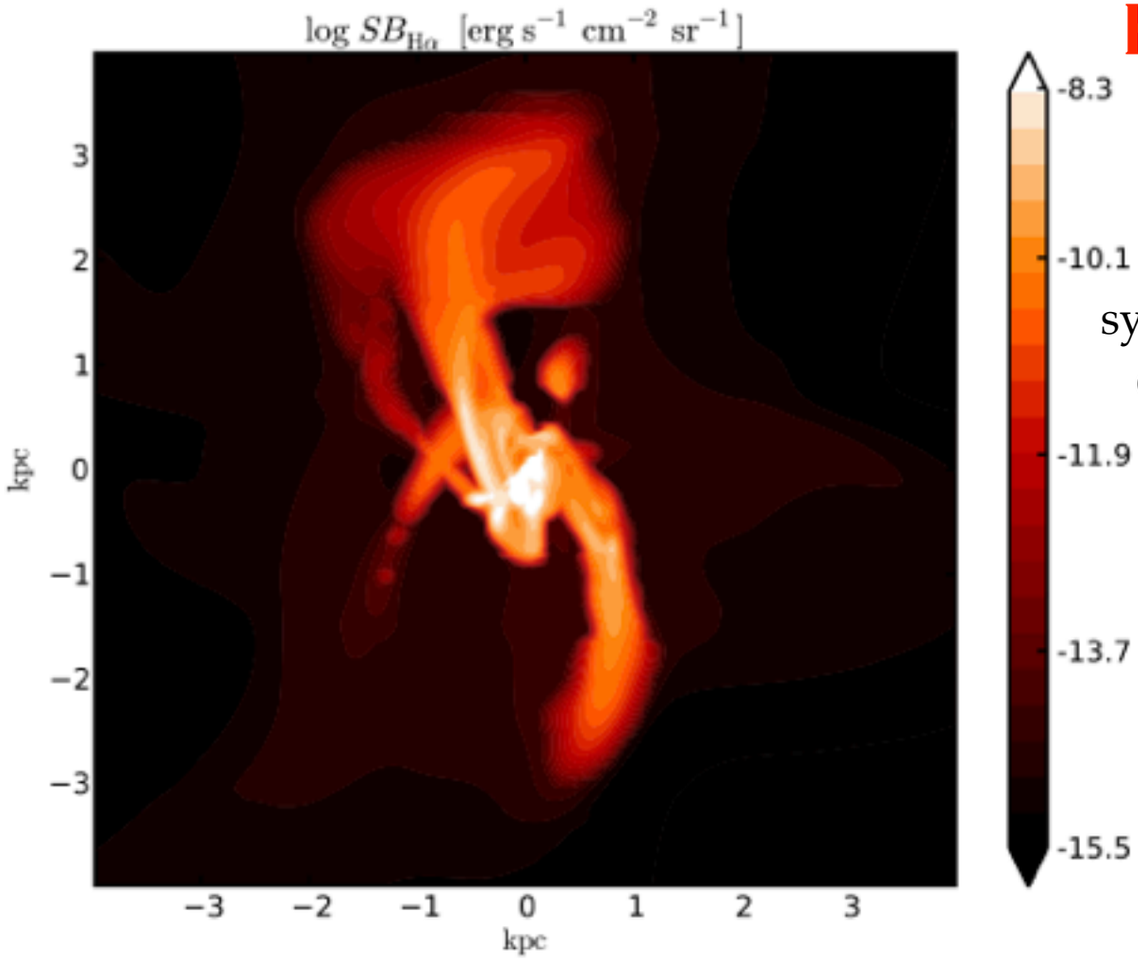

$${\rm Ta_t} > 1$$

**rotating disc dominates**

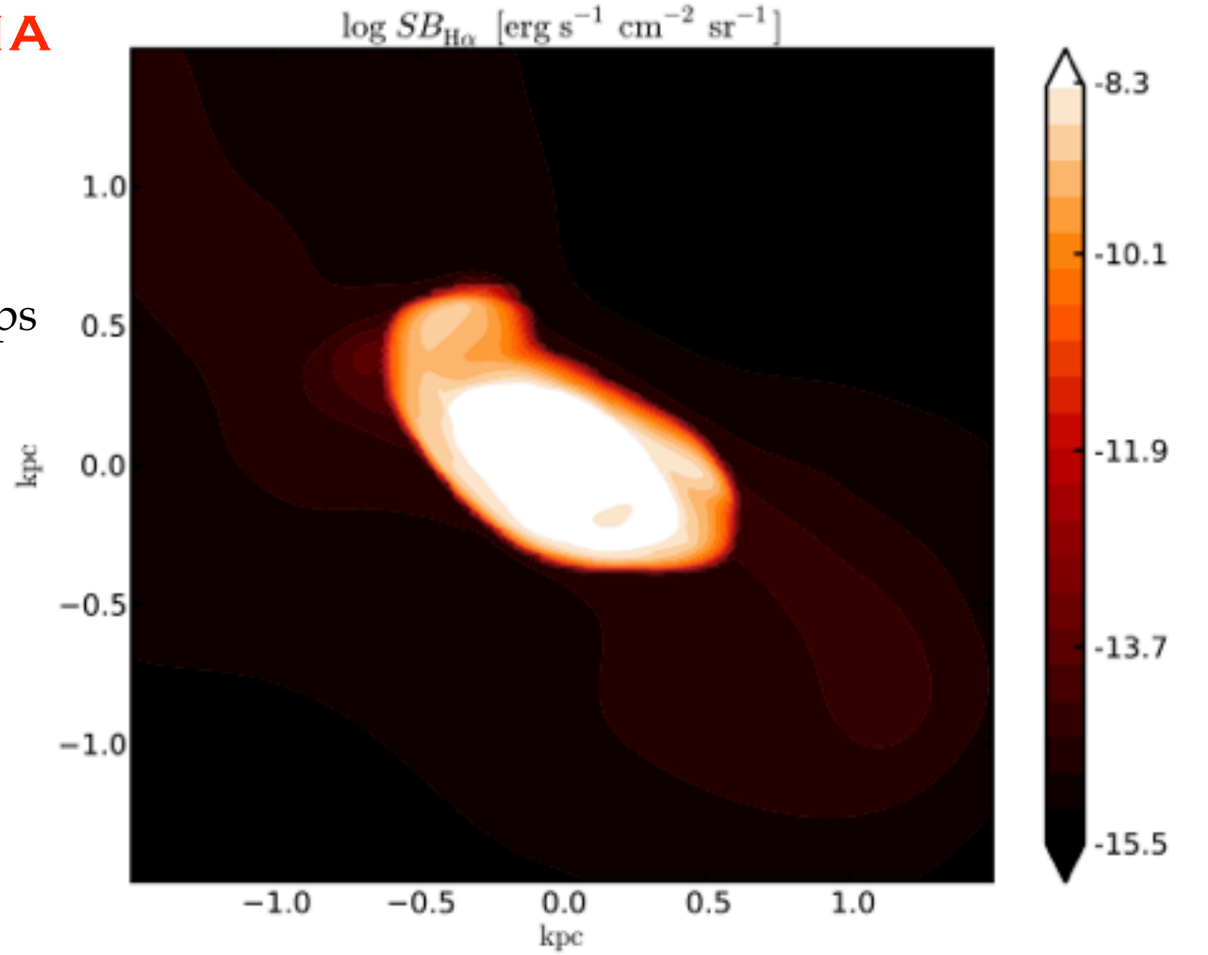
Very high-resolution (0.1 pc) 3D hydrodynamic simulations

CCA has been corroborated by several independent observational and theoretical/simulation studies: e.g., Voit & Donahue 2015, Voit 2015a,b,c; Li & Bryan 2014, 2015; Wong+2014; Russell+2015; Valentini & Brighenti 2015; Yang+2015; Meece+2016; Tremblay+2016; etc.

# Halpha

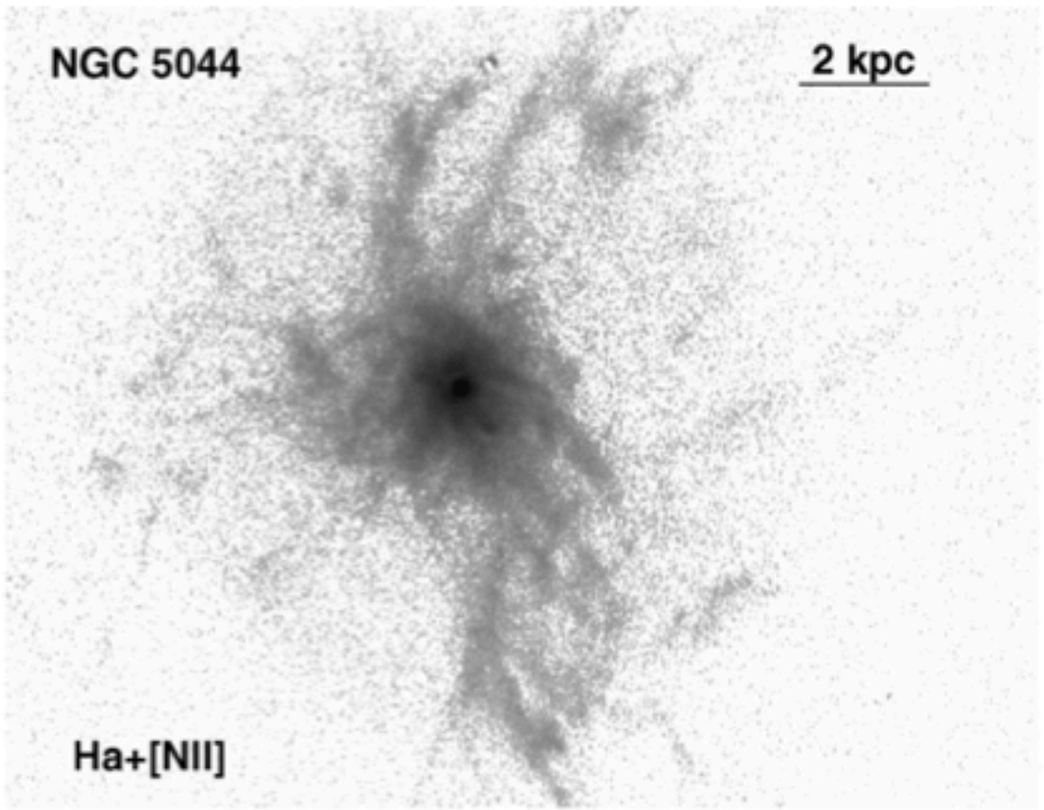



synthetic maps
Gaspari+15

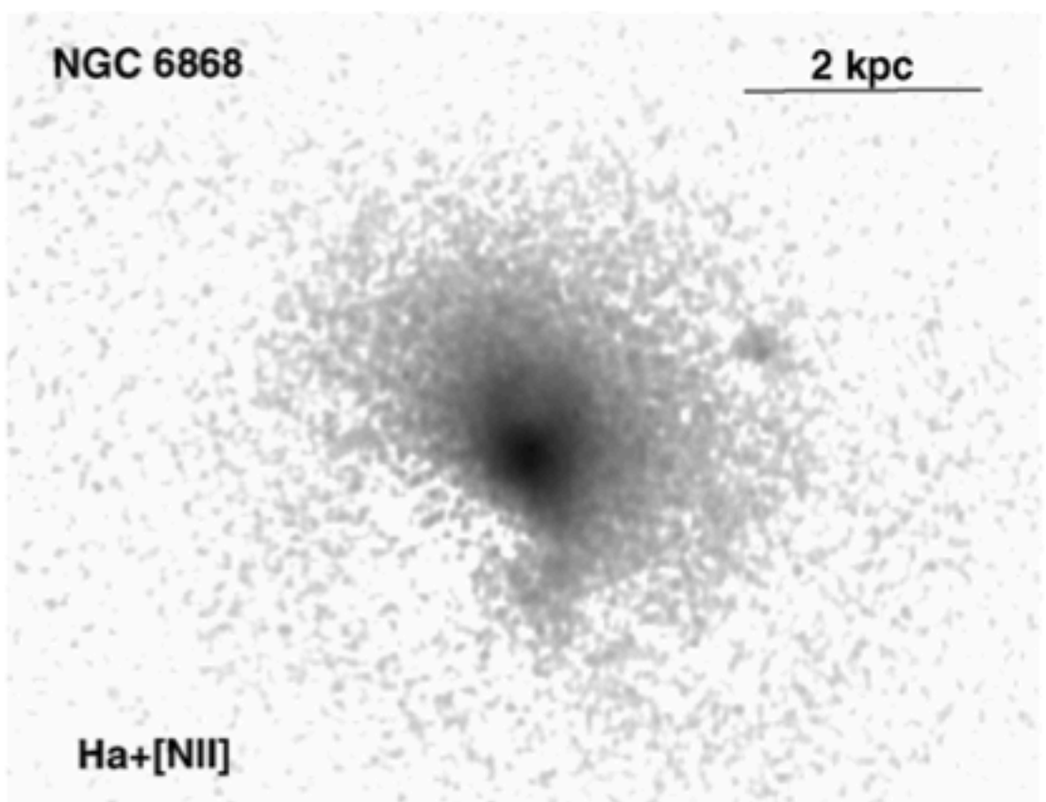



**CCA mode**

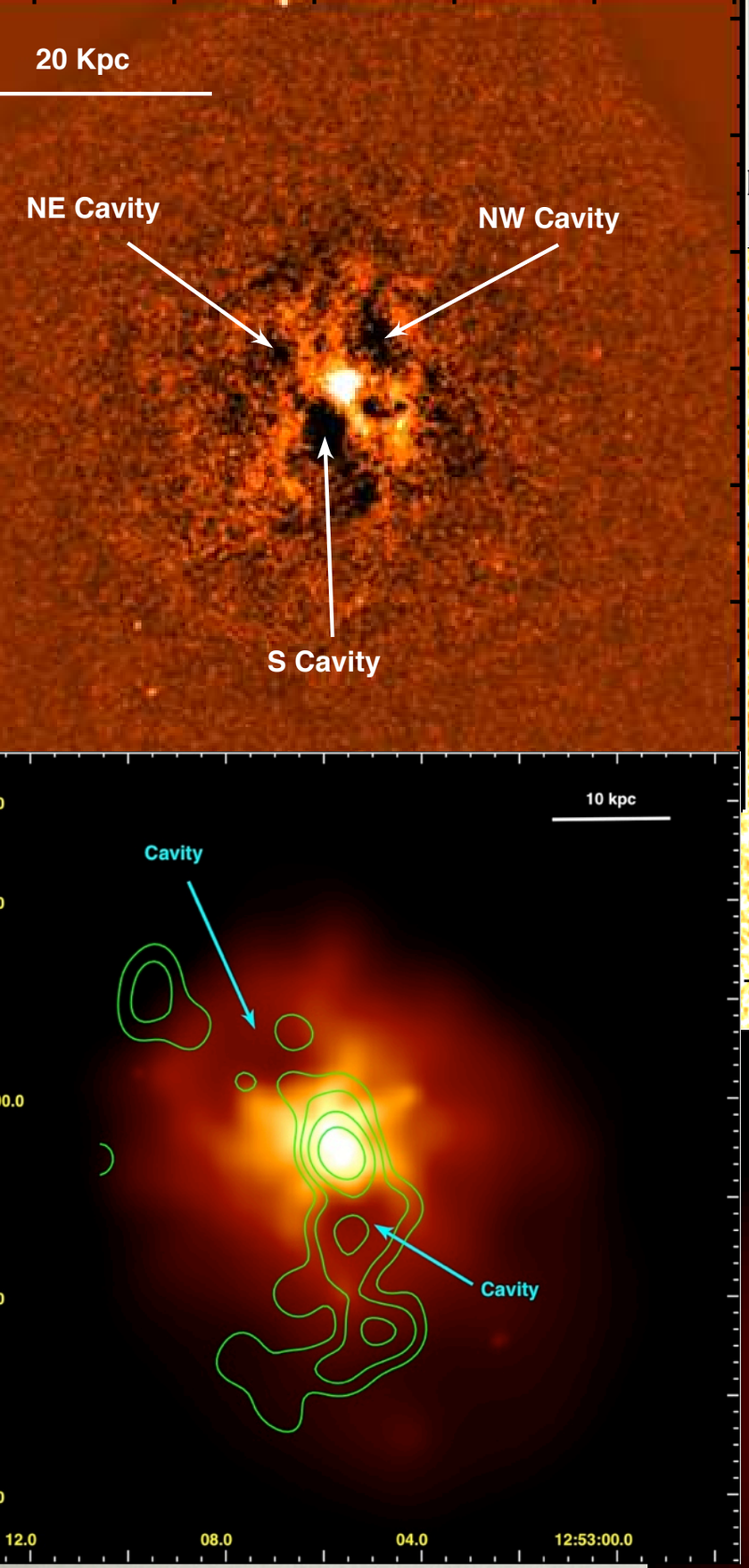
**disc mode**




SOAR data
Werner+14

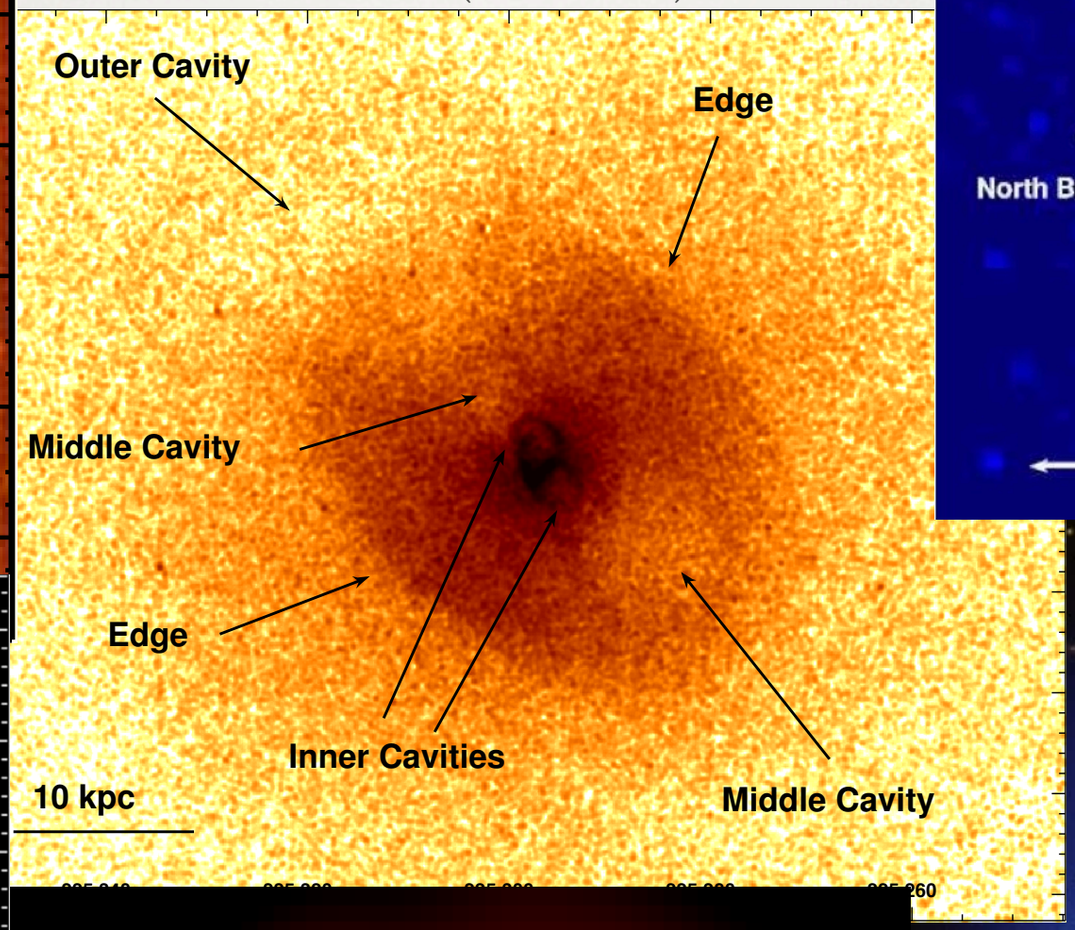


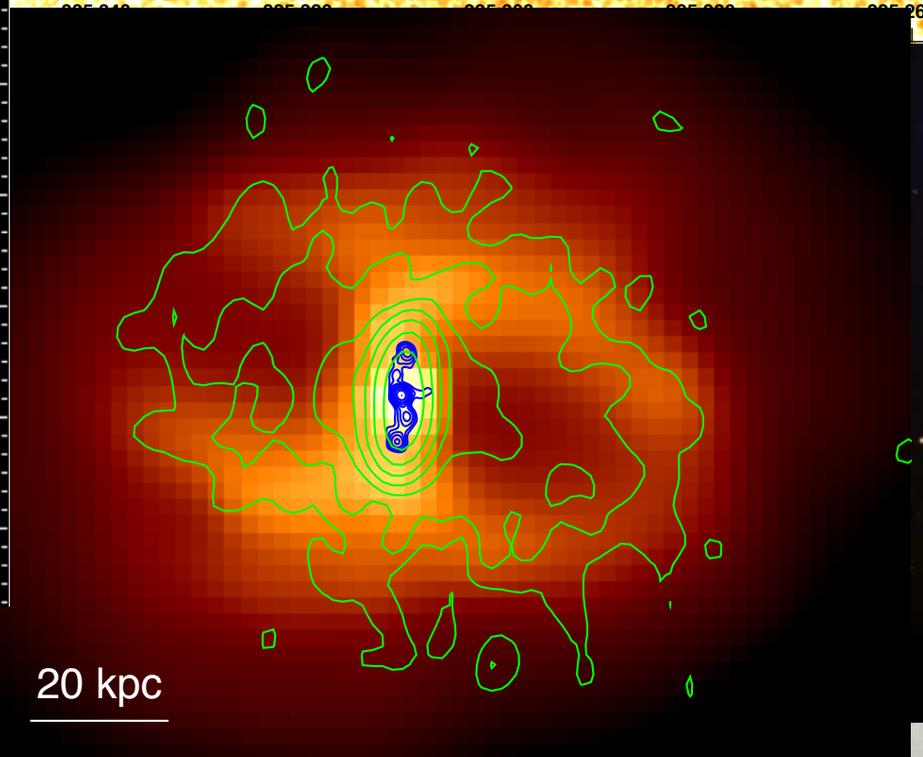
# AGN Feedback



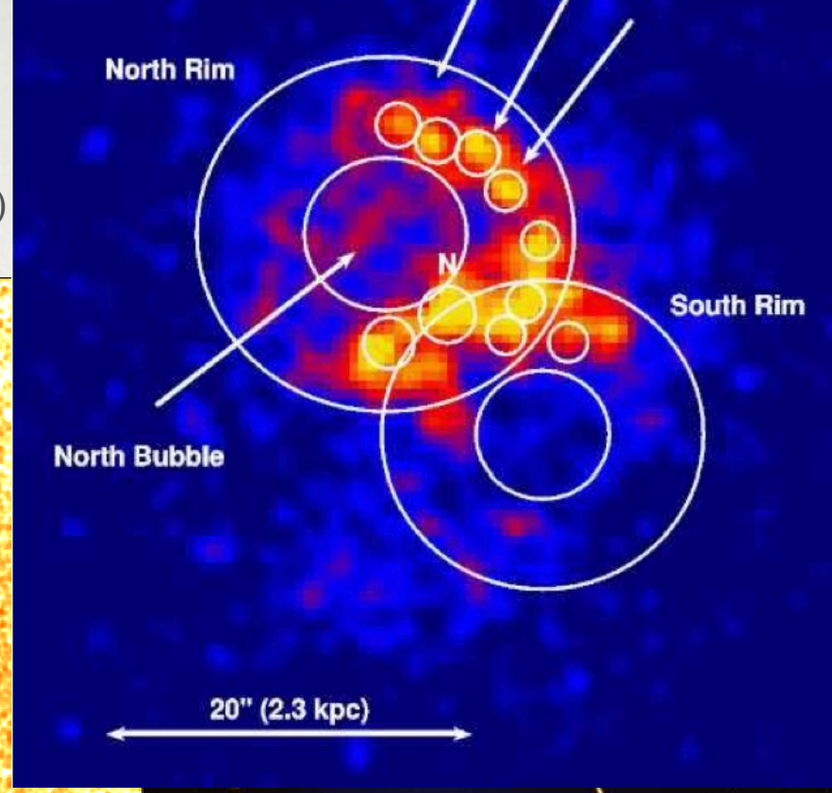

HCG 62 (Gitti+10)

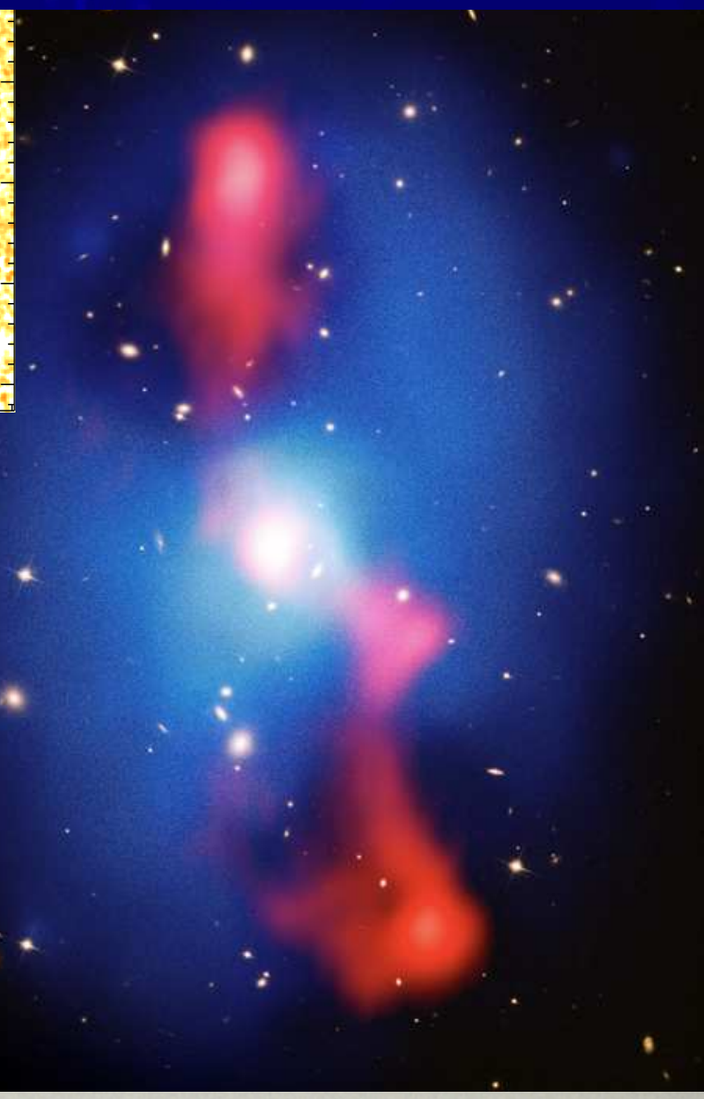
NGC 5044 (David+2009) NGC 5846 (Machacek+11)
NGC 5813 (Randall+11)




RBS 797
(Gitti+11)



MS0735.6 cluster (McNamara+05)

# AGN OUTFLOWS

*ON SCALES < kpc*

AGN blue-shifted absorption lines

UV/X-ray [George+1998; Crenshaw+1999,2003; Kriss+2003; Risaliti +2005; McKernan+2007; Pounds +2003,2009; Cappi+2009; Tombesi+2010, 2011]

optical [Nesvadba+2008, 2011; ...]

21-cm [Morganti+2005, 2007; ...]

molecular [Russell+2014; McNamara+2014, Morganti+2015; ...]

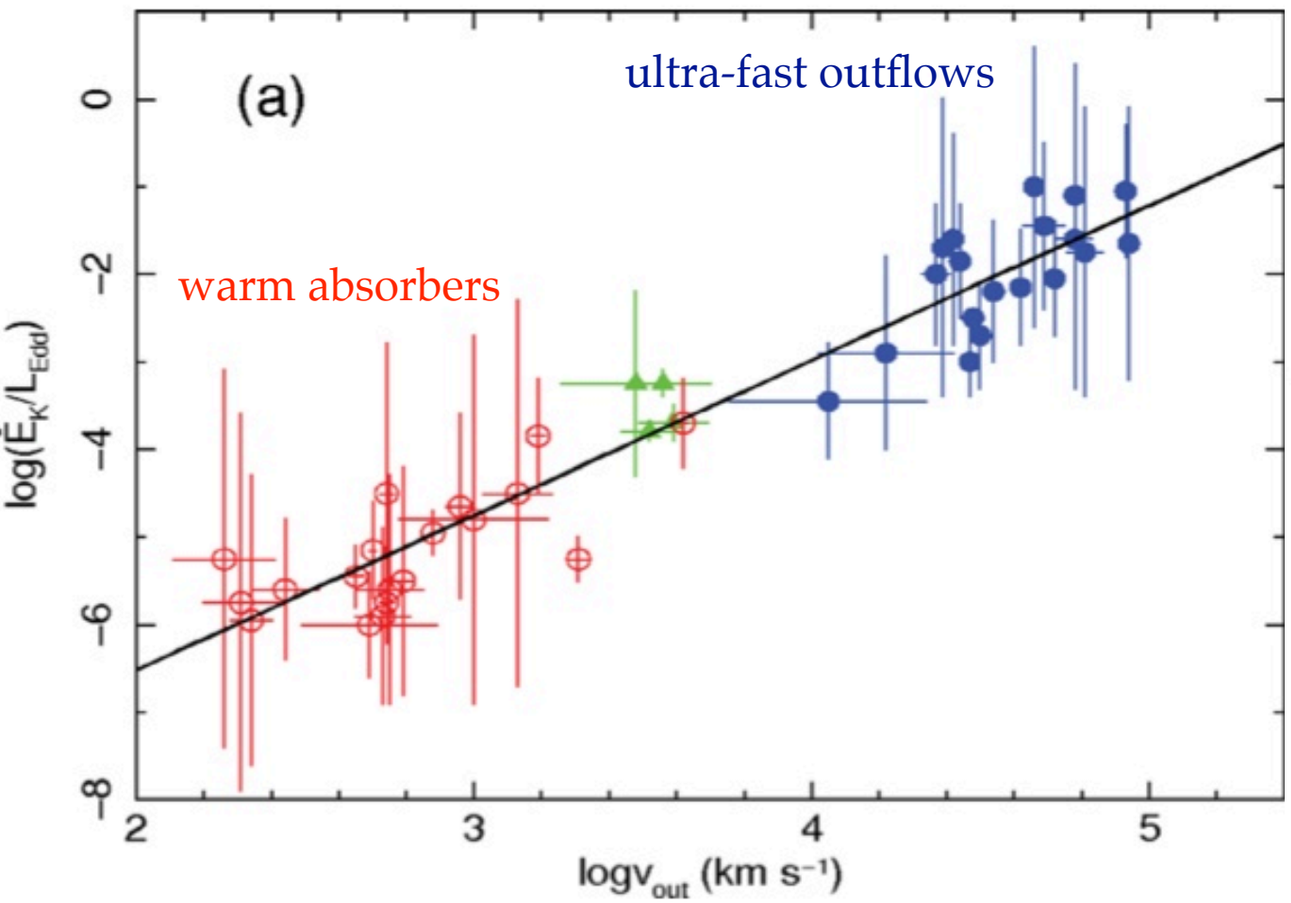
**MASSIVE + SUBRELATIVISTIC**

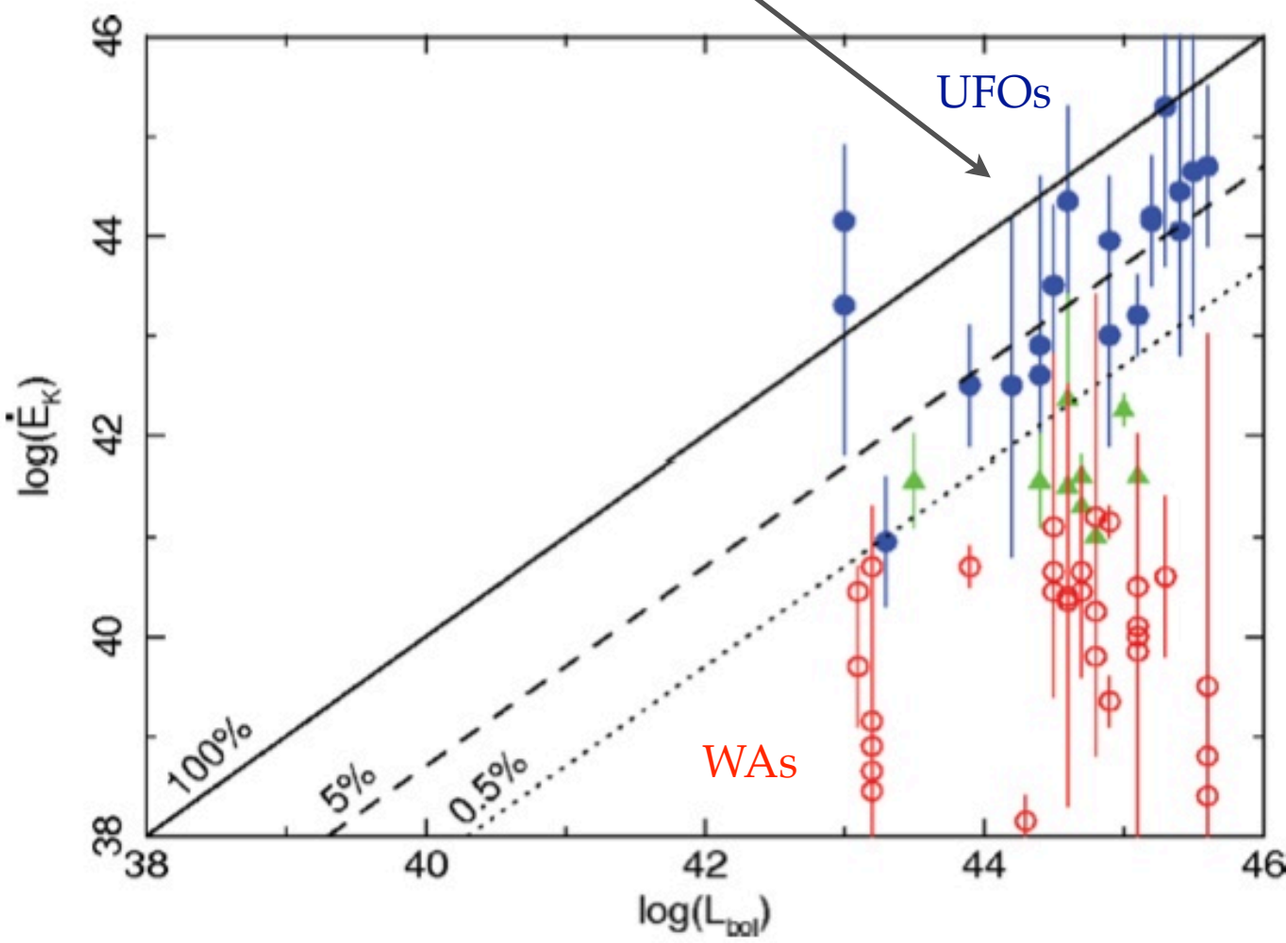
$$v_{\rm out} \sim 10^3 - \text{several } 10^4 \text{ km s}^{-1}$$

$$\dot{M}_{\rm out} \sim 10^0 - 10^2 \ M_\odot \, \text{yr}^{-1}$$

with substantial kinetic power

Tombesi et al. 2013



# AGN OUTFLOWS DRIVEN BY CCA FEEDBACK

**Solving the cooling flow problem (mass sink)**

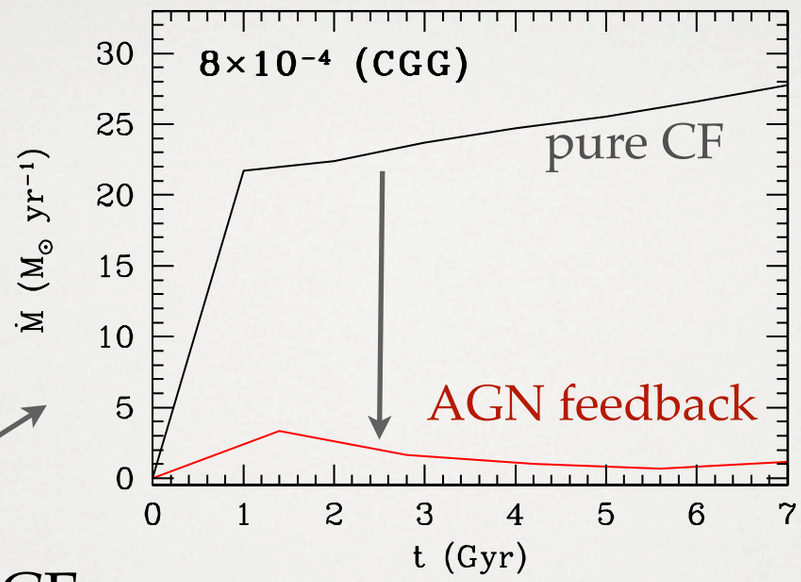
- Quenched cooling: < 5-10% CF
- Cool core preserved
- Mechanical efficiencies:

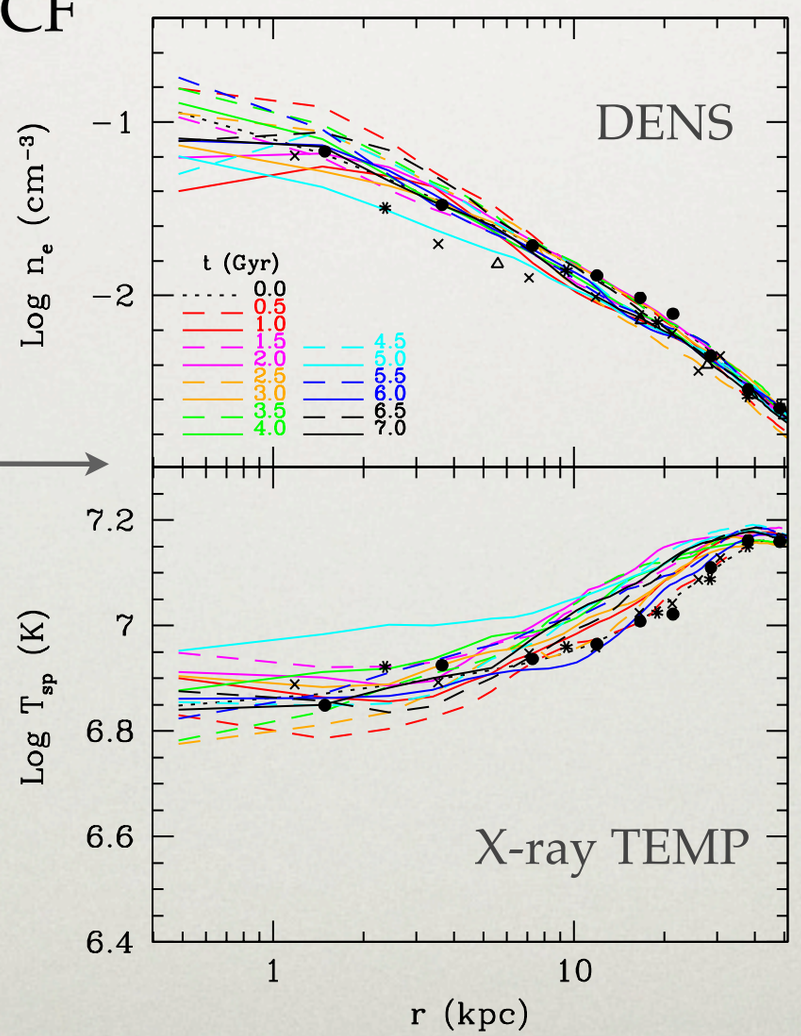
  ~ $5 \times 10^{-4}$ - $5 \times 10^{-3}$

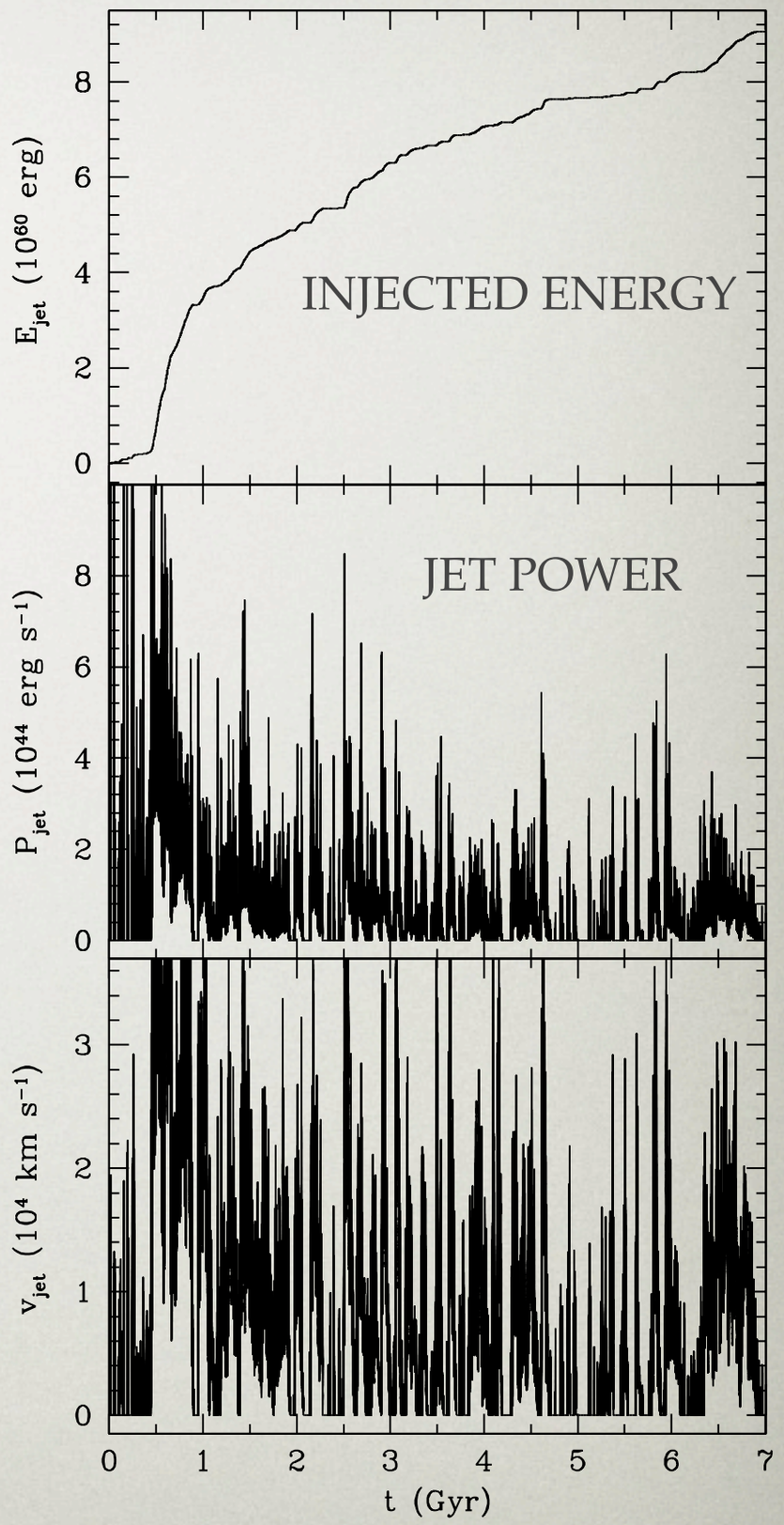
  isolated galaxies --> clusters

galaxy group NGC 5044

Gaspari et al. 2012




self-regulated AGN feedback 3D hydro simulation

# SELF-REGULATED CCA/AGN FEEDBACK

$\mathcal{L} > \mathcal{H}$

↓

$t_{\rm cool}/t_{\rm ff} \lesssim 10$

↓

thermal instability condensation

↓

CCA rain onto SMBH

↓

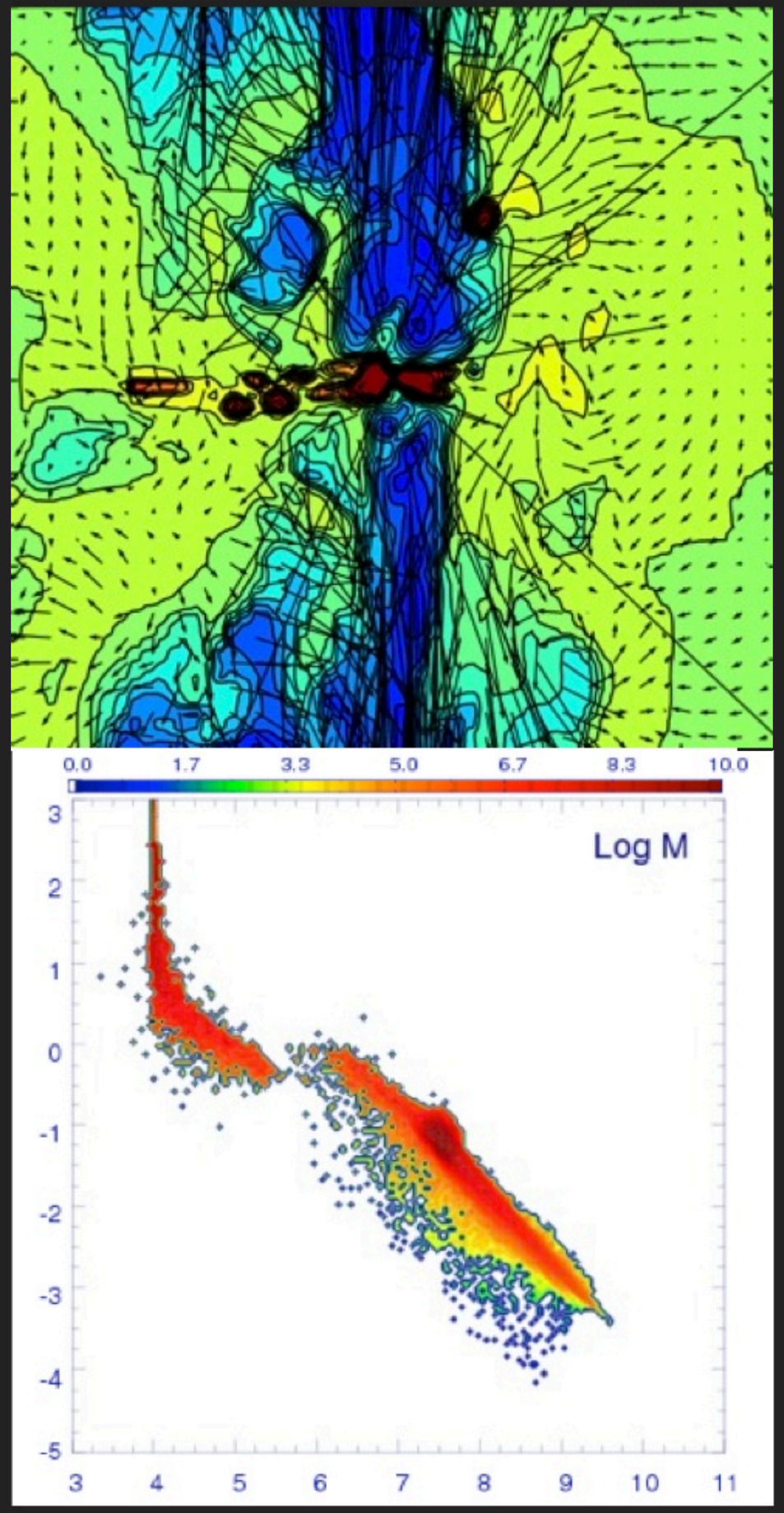
$\frac{1}{2}\dot{m}_{\rm out} v_{\rm out}^2 = P_{\rm out} = \epsilon\, \dot{M}_{\rm acc} c^2$

↓

AGN outflows boosted

↓

$\mathcal{L} < \mathcal{H}$




Gaspari+12-15

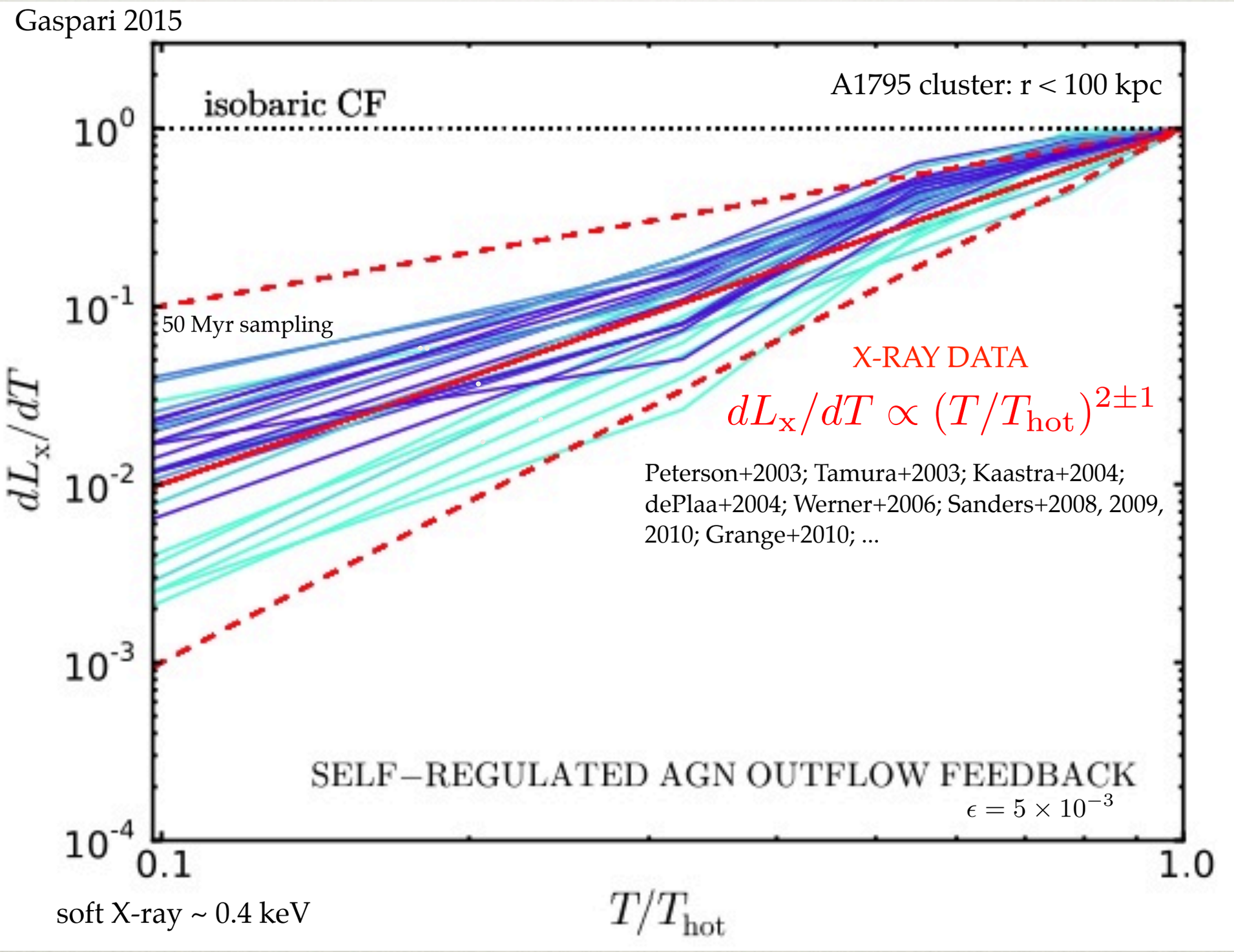
A1795 cluster core

# QUENCHING THE SOFT X-RAY SPECTRUM

stronger CCA

stronger heating

Gaspari 2015

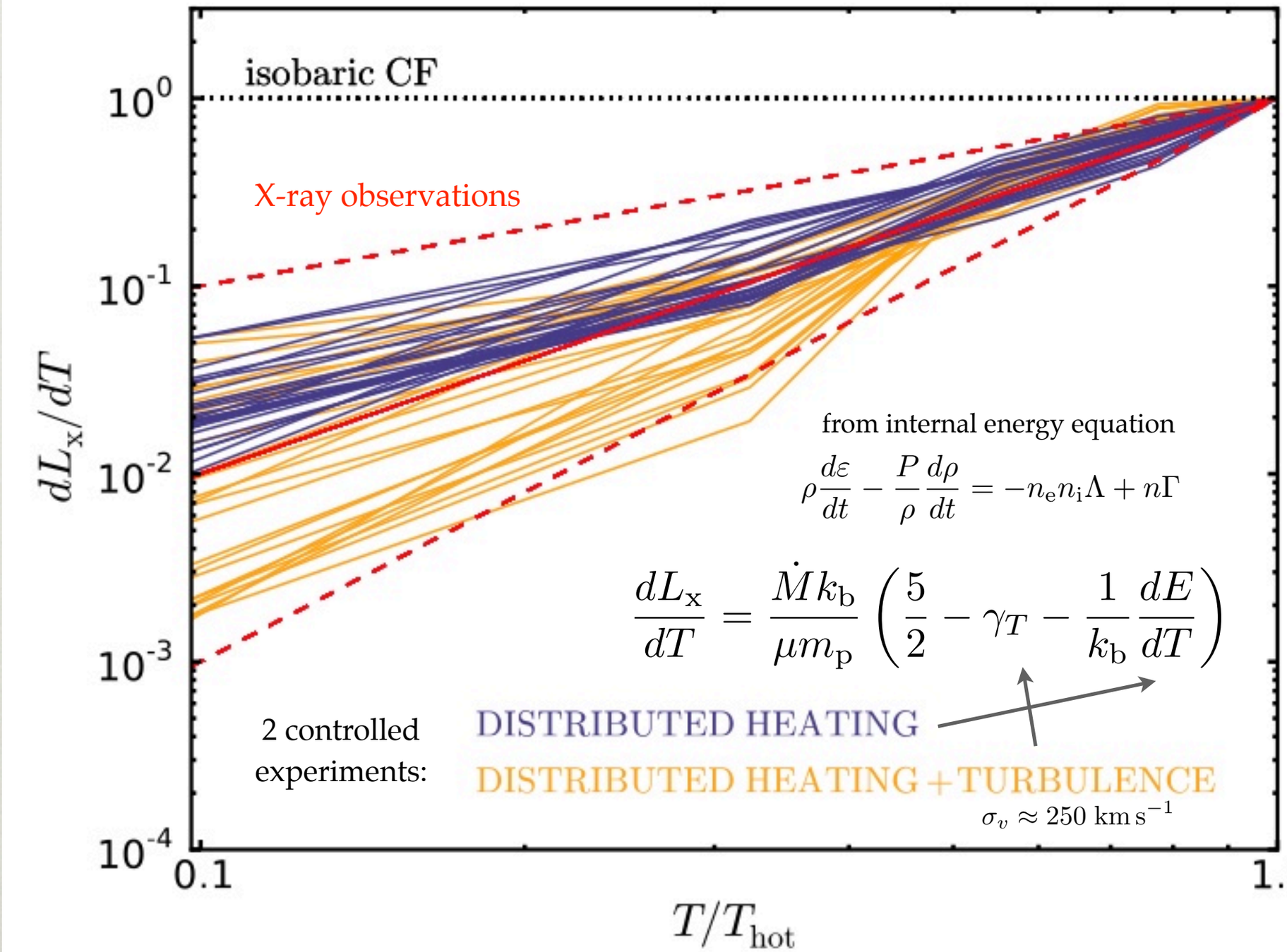



soft X-ray ~ 0.4 keV

High-resolution (300 pc) 3D hydrodynamic (PPM) simulations

# QUENCHING THE SOFT X-RAY SPECTRUM

Gaspari 2015



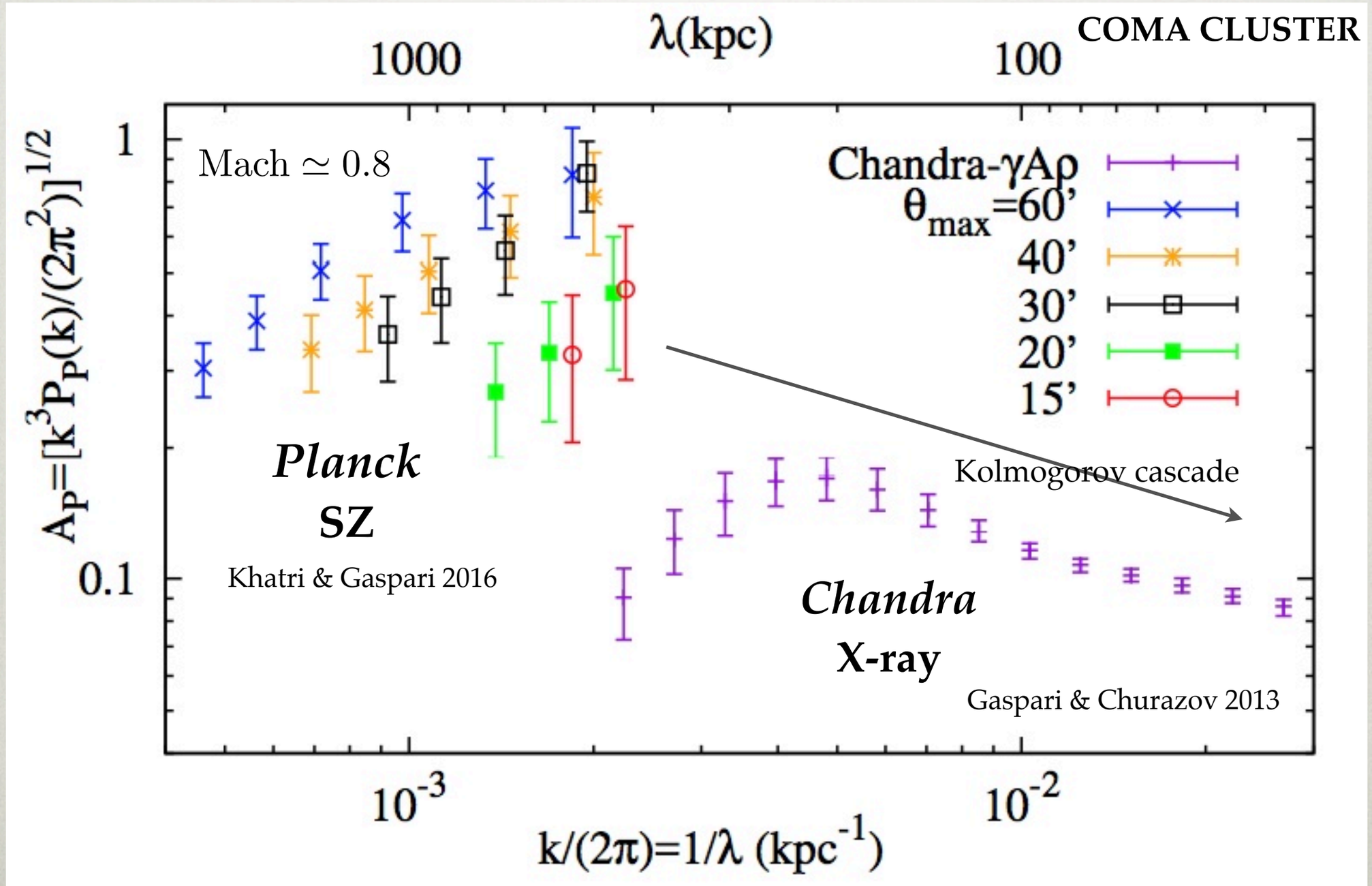

1. AGN outflows deposit relatively more heat in the inner cooler phase => inside-out heating mechanism

2. non-isobaric cooling ($\gamma_T > 0$): turbulence becomes transonic in the cooler phase => larger diffusion and variance

# ICM POWER SPECTRUM

## PROBING TURBULENCE & CONDUCTION

from 3D hydro simulations: $\delta\rho/\rho \sim \mathrm{Mach}_{1\mathrm{D}}$ [Gaspari & Churazov 2013; Gaspari et al. 2014]




FUTURE: Ms exposure is crucial to retrieve SBx fluctuations and thus constraining ICM physics

# SUMMARY

## FEEDING

- chaotic cold accretion [CCA]
- nonlinear TI: multiphase condensation
- accretion rate boosted up to 100x
- multiphase rain, e.g., H$\alpha$ filaments
- tight symbiosis SMBH - whole galaxy

## FEEDBACK

- massive, subrelativistic AGN outflows
- suppress total cooling rate by 20x
- quench soft X-ray spectrum: alpha ~ 2
- preserve CC structure for several Gyr
- perturbations: ICM power spectrum

**SELF-REGULATED LOOP**

$$P_{\rm out} = \epsilon \, \dot{M}_{\rm BH} c^2$$