THE SELF-REGULATED AGN FEEDBACK LOOP

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SELF-REGULATED AGN FEEDBACK

AMR zoom-in 3D simulations (FLASH)

FEEDING

- cold versus hot mode
- linking host scale to sub-pc scale
- beyond classic Bondi and thin disc
- turbulence, cooling, heating, rotation: **chaotic cold accretion [CCA]**

MG+2013-2015 sims

galactic 52 kpc --> 20 Rs

10 million range

FEEDBACK

- amount of energy released
- deposition of energy
- mechanical versus thermal
- bubbles, shocks, metal uplift, turbulence, L_x-T_x <---> observations

MG+2009-2015 sims

large scales: 100 pc --> 2 Mpc

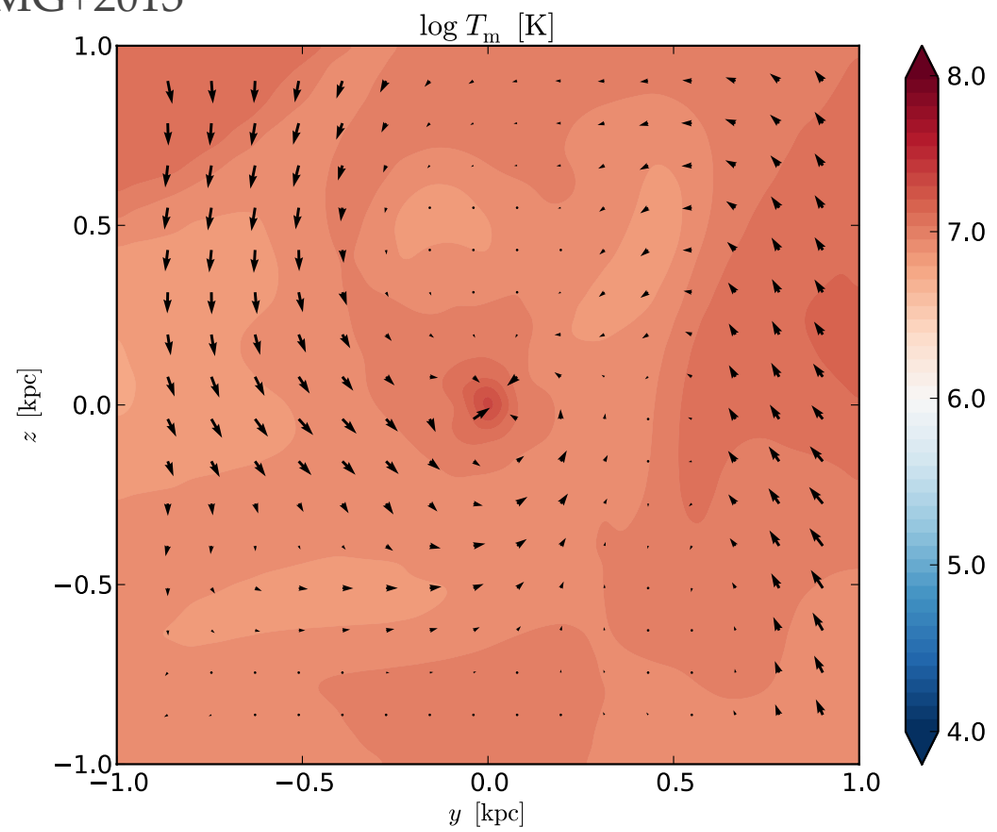
galaxy cluster

SELF-REGULATED LOOP

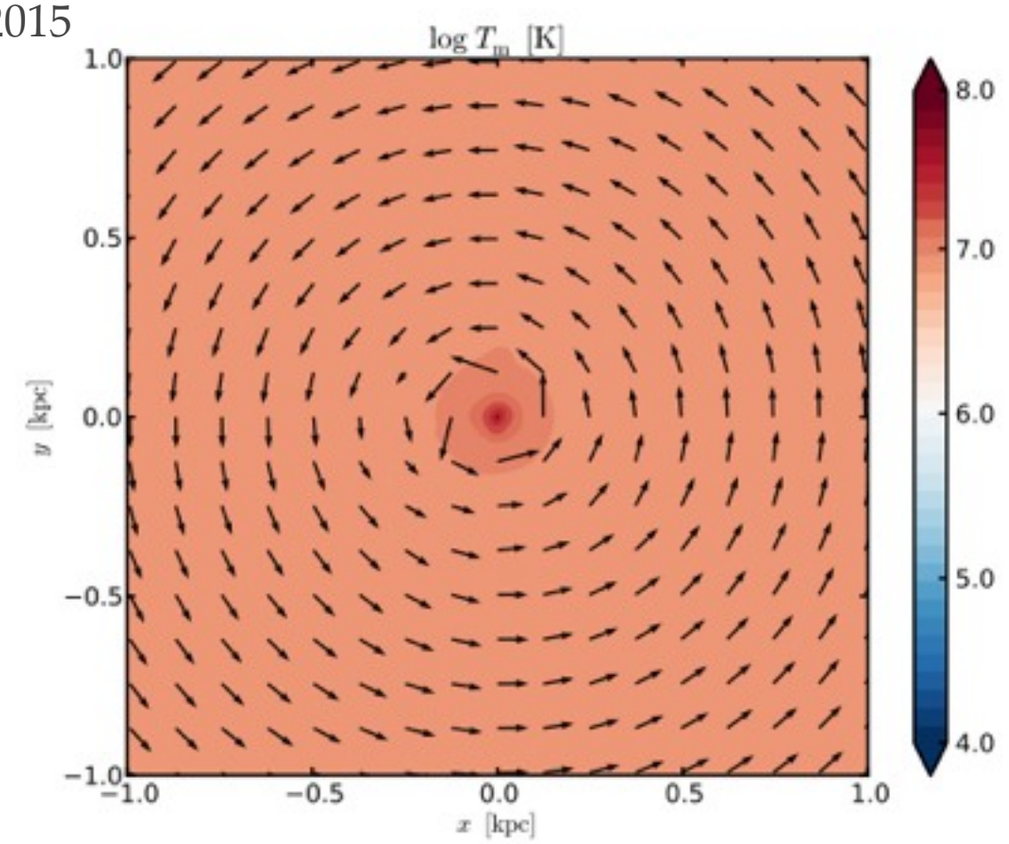
$$P_{\rm out} = \epsilon \dot{M}_{\rm BH} c^2$$

HOT ACCRETION

MG+2013



MG+2015



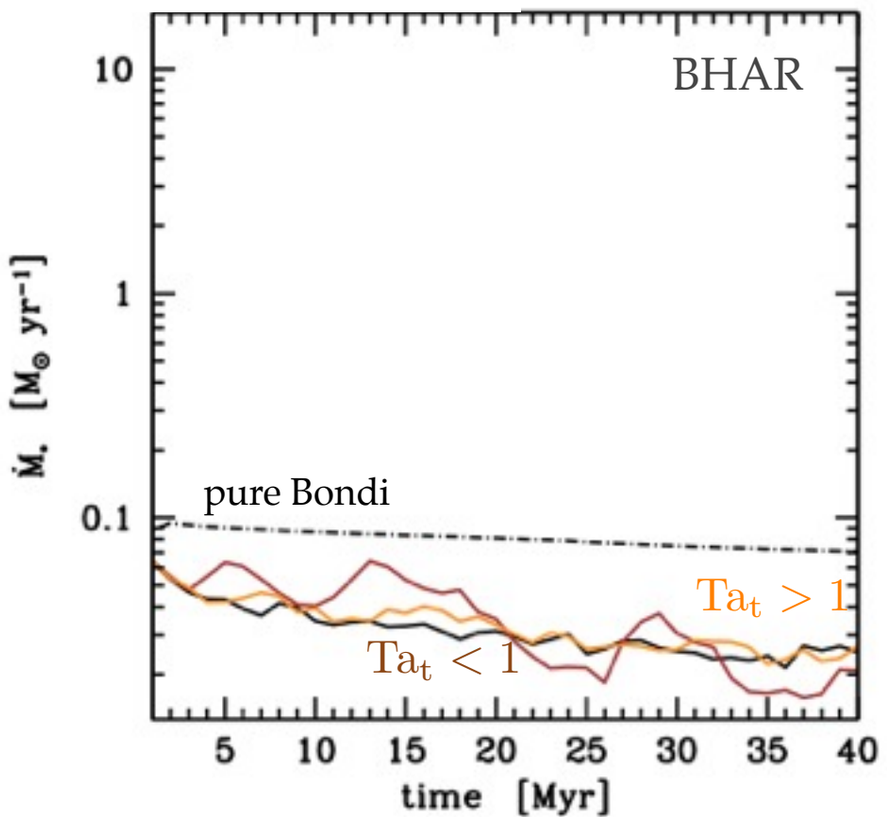
rotation < **turbulence**

$\mathrm{Ta_t} \equiv v_{\rm rot}/\sigma_v < 1$

$\sigma_v \sim 100\,\mathrm{km\,s^{-1}}$

massive ETG (NGC 5044)

SMBH: $M_{bh} = 3\times10^9\ M_\odot$



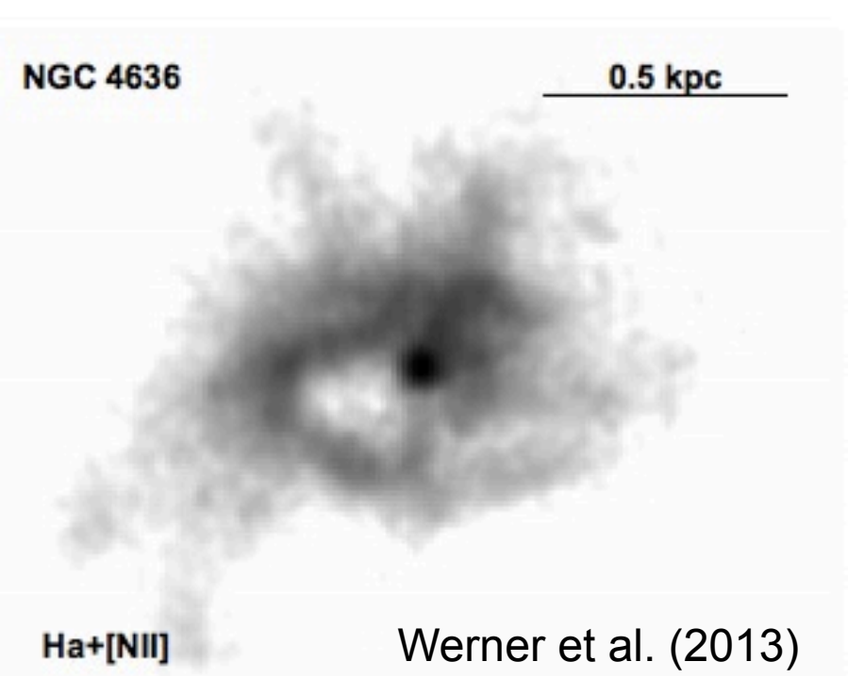
rotation > turbulence

$\mathrm{Ta_t} \equiv v_{\rm rot}/\sigma_v > 1$

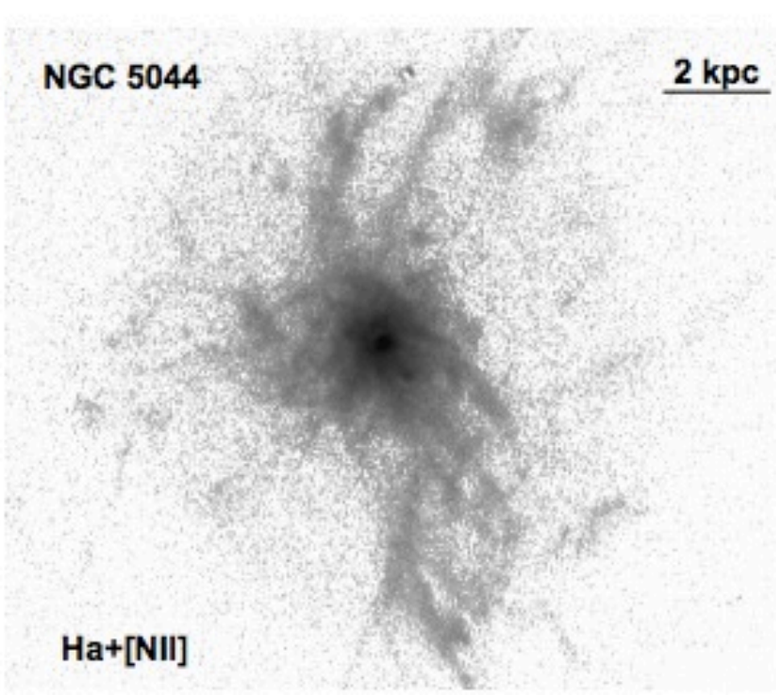
$v_{\rm rot,gas} \approx 100\ \mathrm{km\,s^{-1}}$

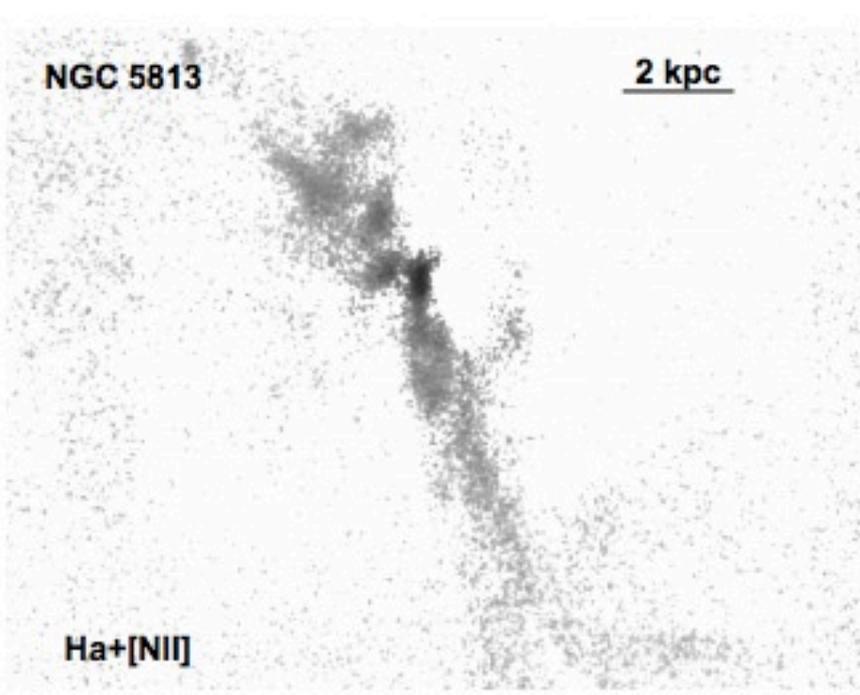
$\dot{M}_{\rm Bondi} = 4\pi(GM_{\rm BH})^2\rho_\infty/c^3_{s,\infty}$

Perseus
Fabian et al.



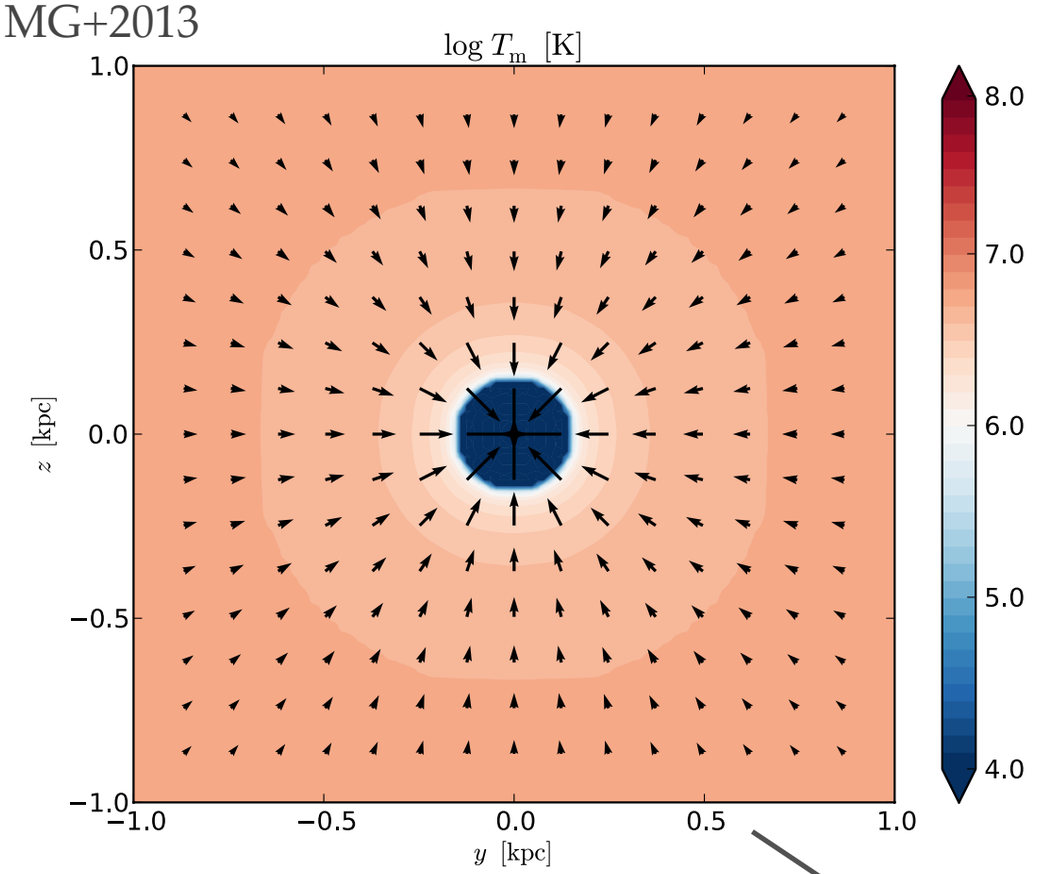
Werner et al. (2013)



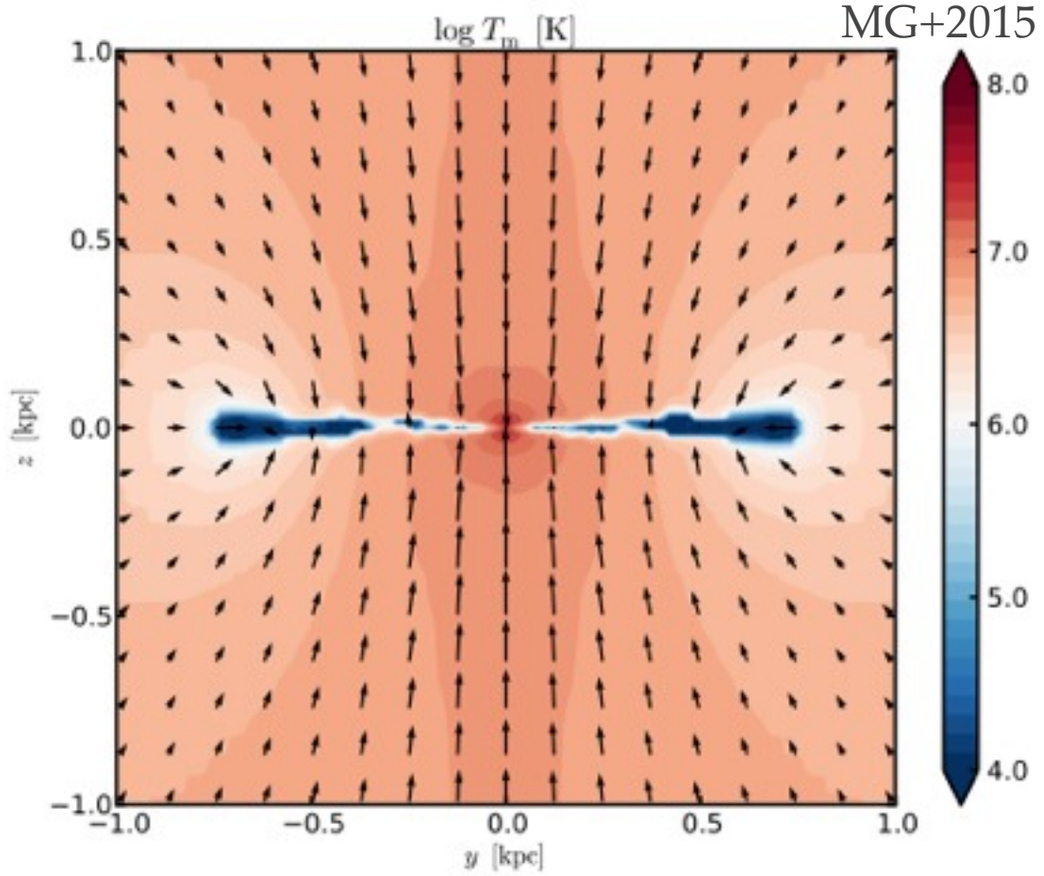


PURE COLD ACCRETION

MG+2013

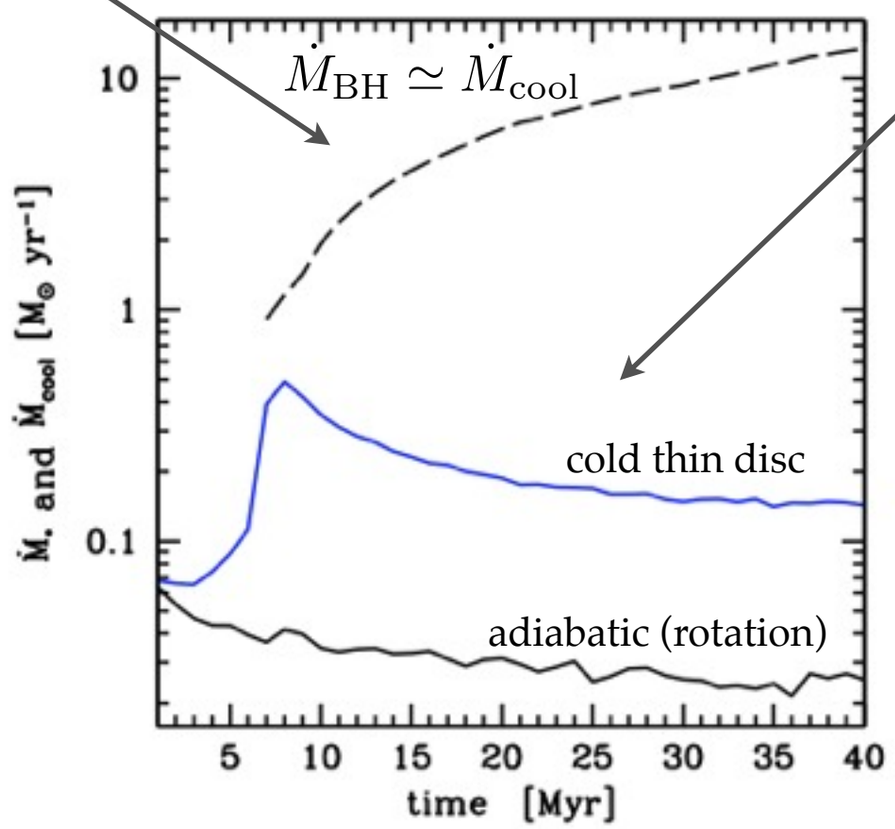


MG+2015



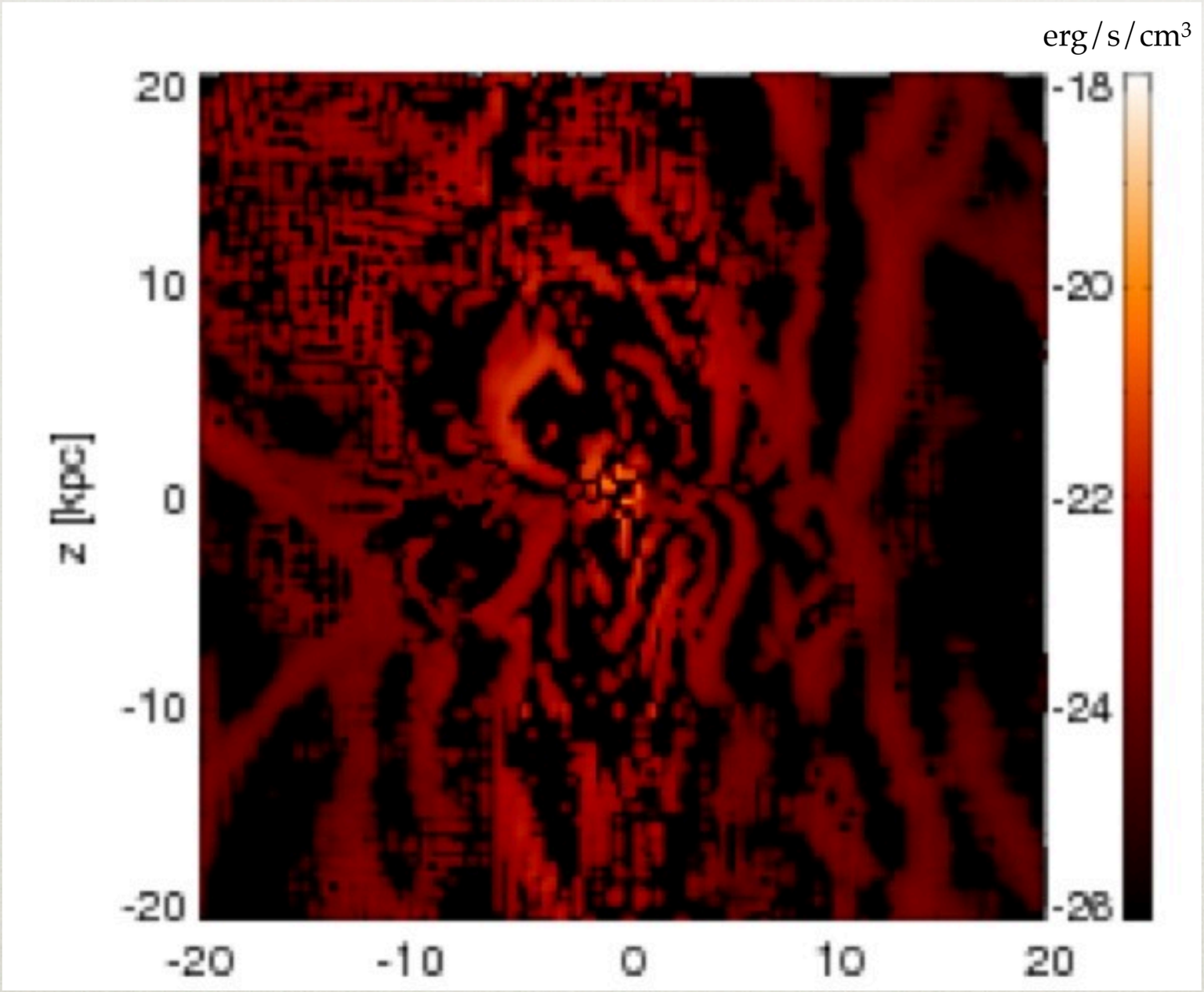
no rotation

rotation



GLOBAL THERMAL EQUILIBRIUM

AGN outflow feedback: net heating deposition

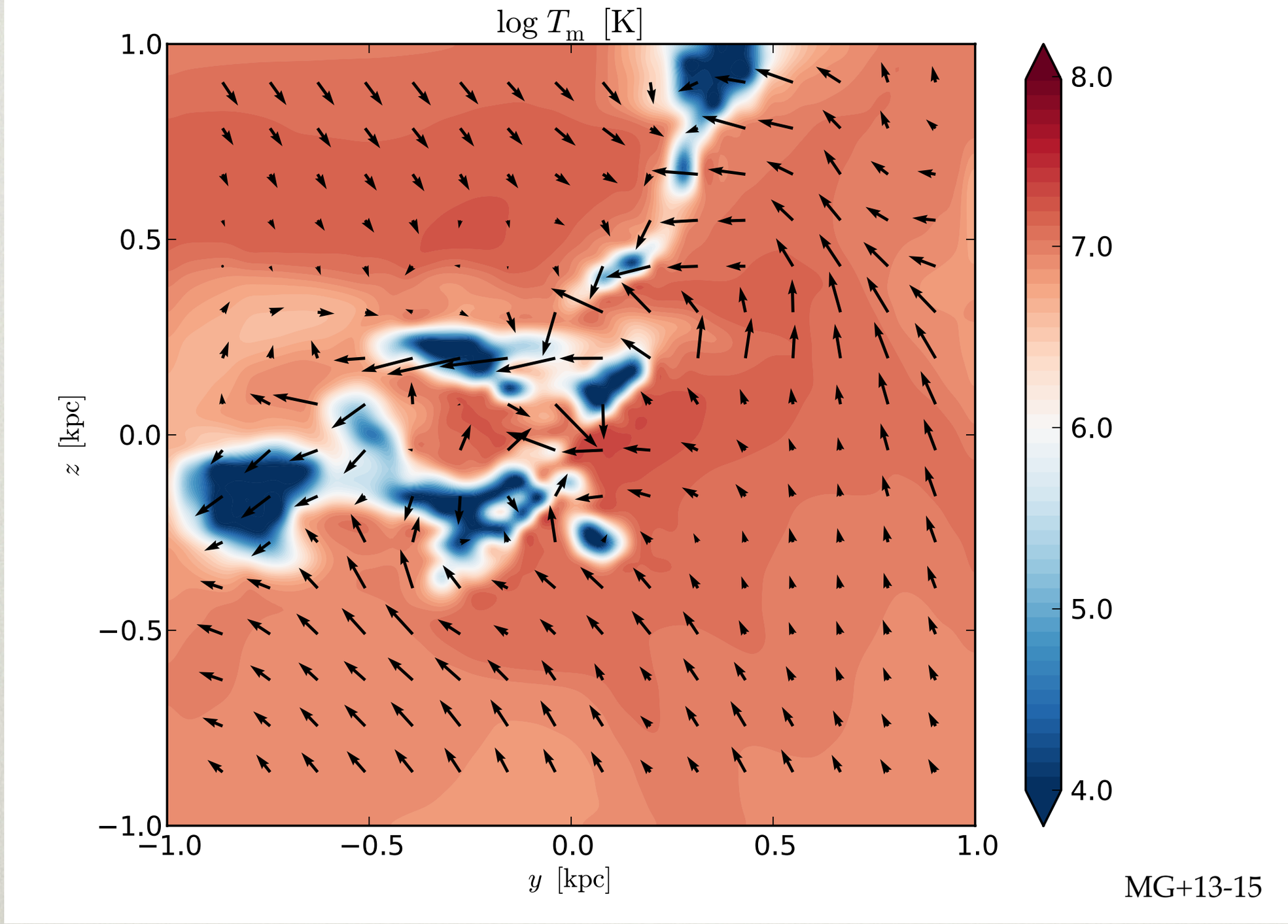


internal energy increase
(averaged over 1 Gyr)

MG+2012

$$\mathcal{H} \sim \langle \mathcal{L} \rangle$$

CHAOTIC COLD ACCRETION [CCA]



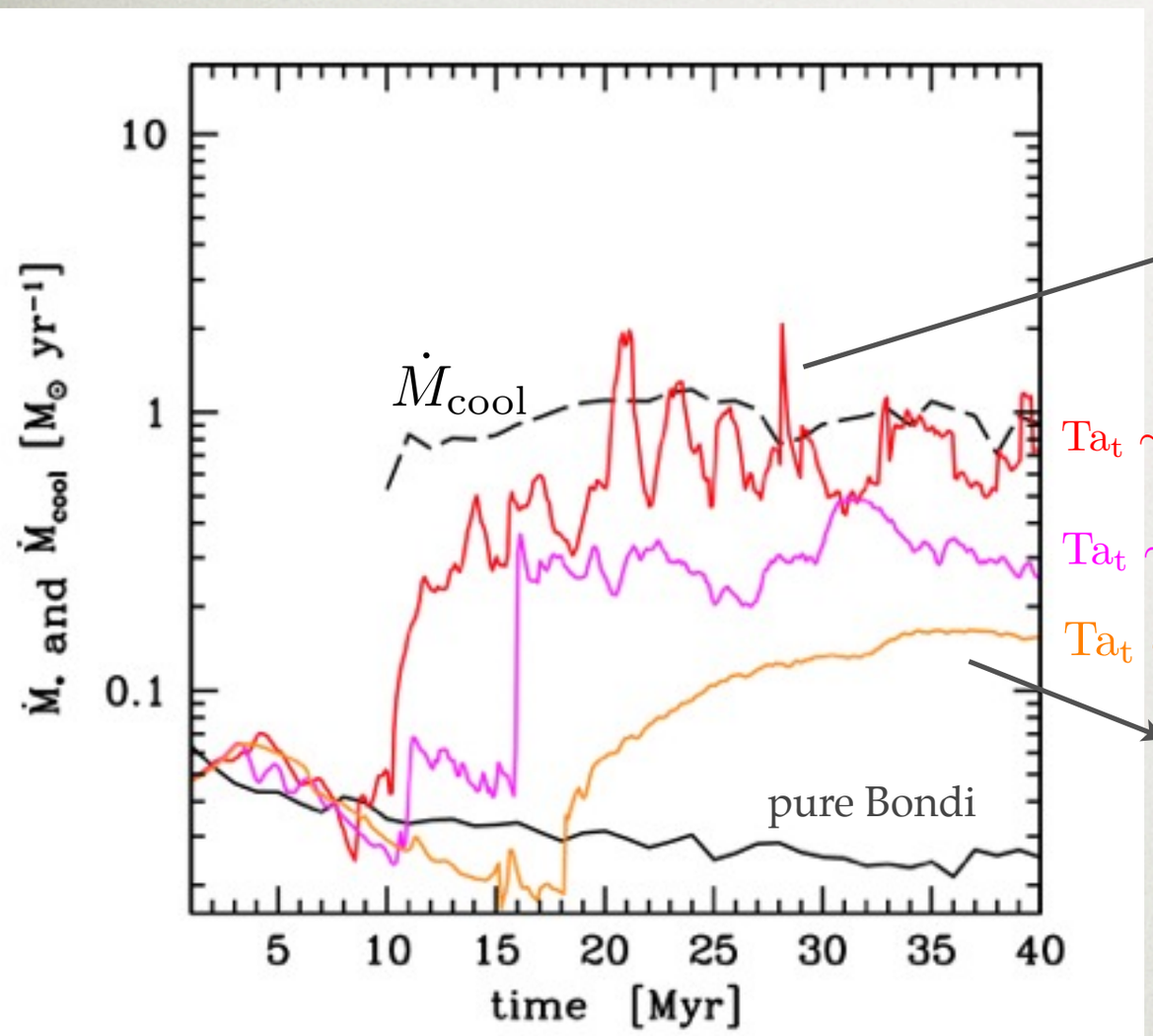
COOLING + TURBULENCE + AGN HEATING

$\sigma_v \sim 100\,\mathrm{km\,s^{-1}}$ $\mathcal{H} \sim \langle \mathcal{L} \rangle$

CHAOTIC COLD ACCRETION [CCA]

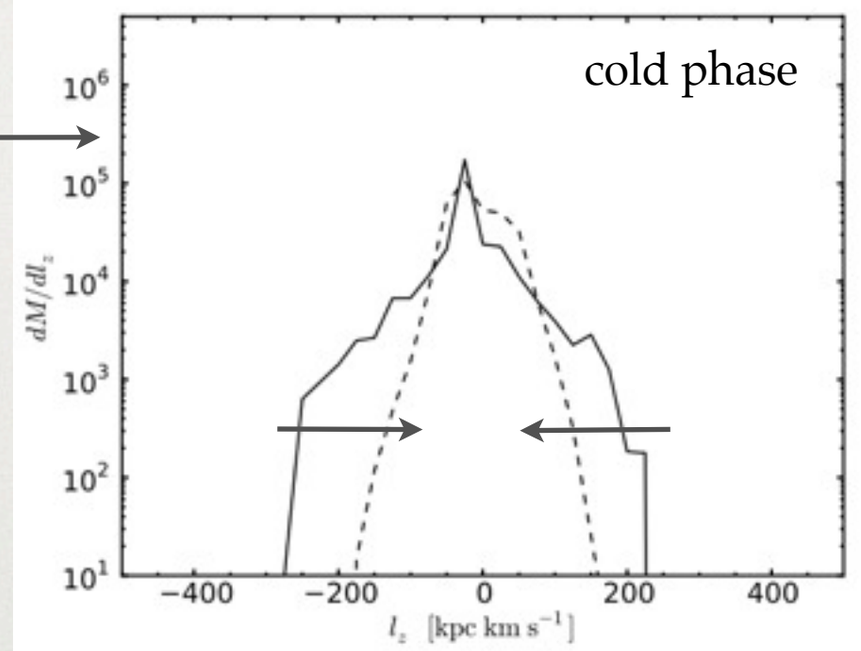
$$\dot{M}_{\rm BH} \sim 100\,\dot{M}_{\rm Bondi} \sim \dot{M}_{\rm cool}$$

MG+15



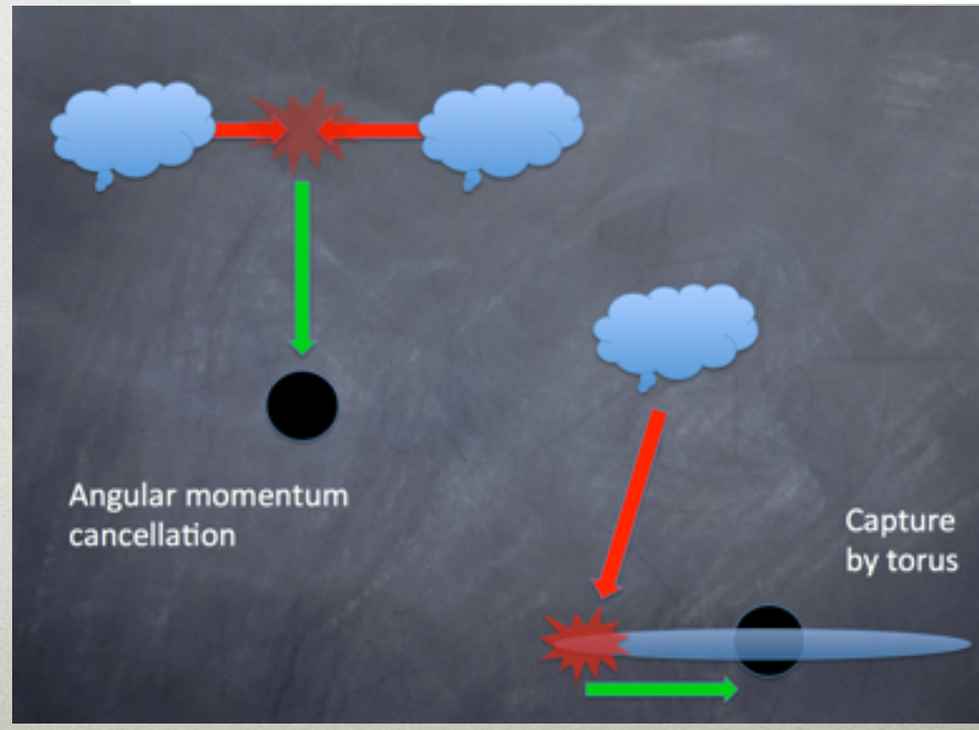
$\rm Ta_t < 1$

CCA dominates



$\rm Ta_t > 1$

disc dominates



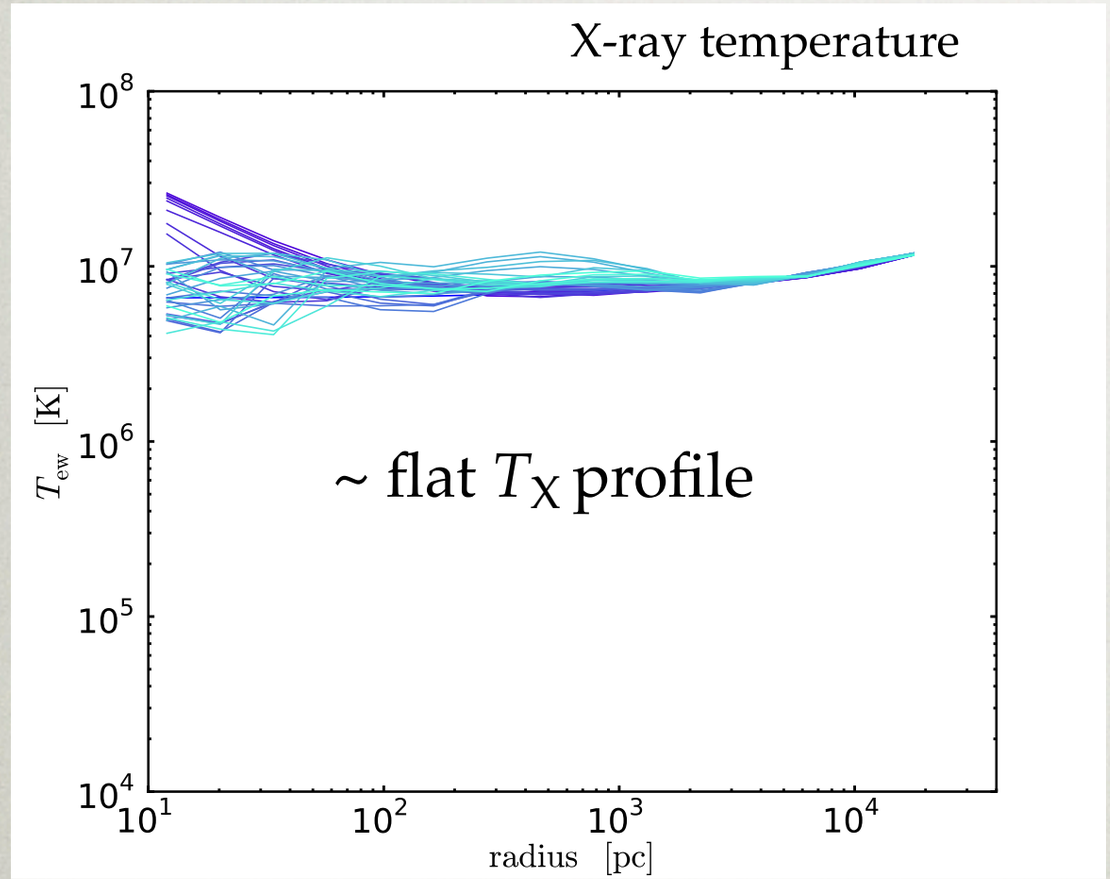
COLD vs HOT

ACCRETION

- $t_{\rm cool}/t_{\rm ff}$ **< 10 => condensation & TI**

chaotic cold accretion

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

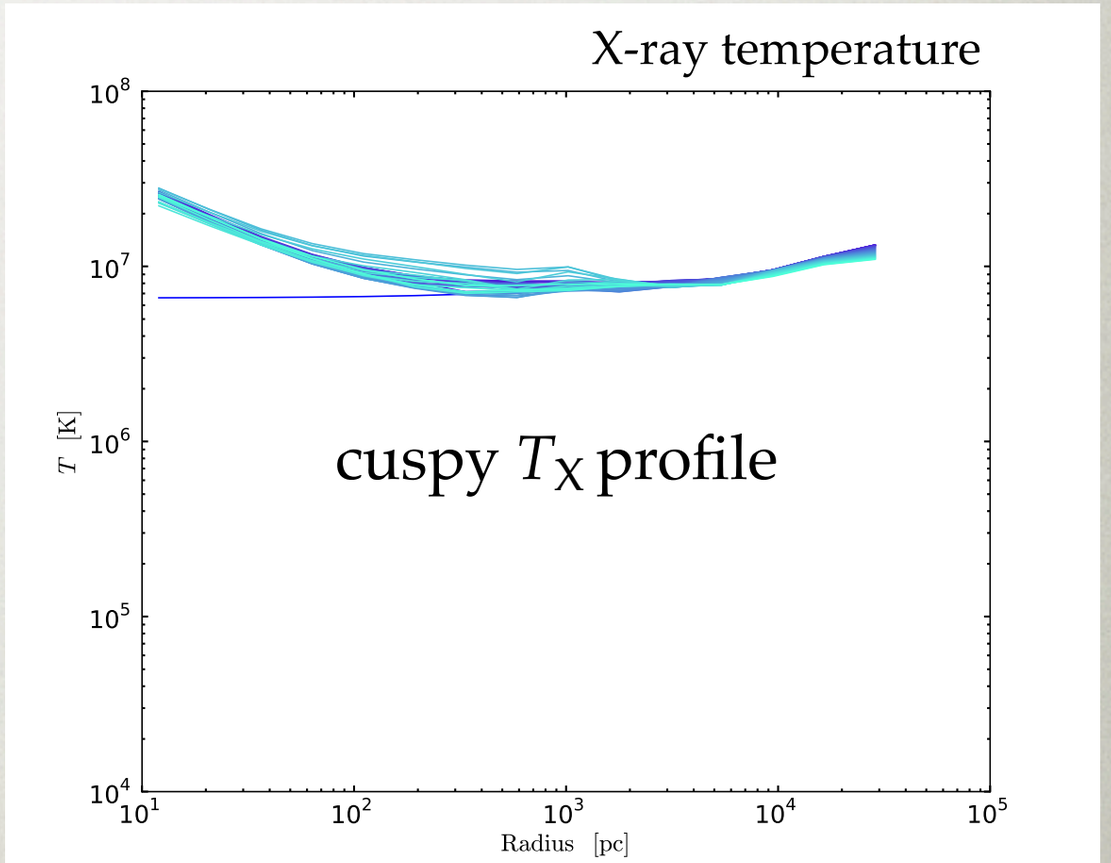


e.g. NGC 3115 (Wong et al. 2014)
NGC 4261, 4472 (Humphrey et al. 2009)
M87 (Russell et al. 2015)

- $t_{\rm cool}/t_{\rm ff}$ **>> 10 => overheated phase**

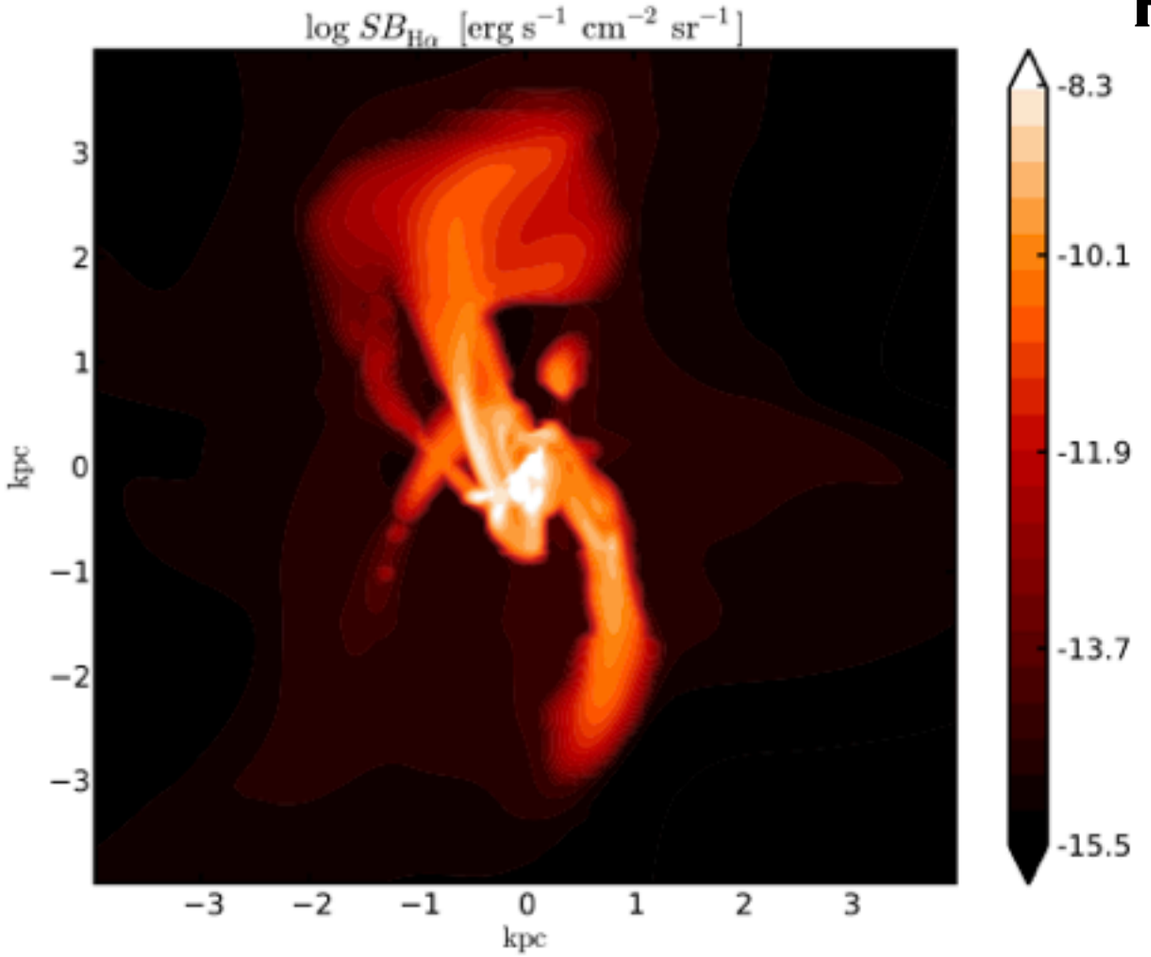
stifled Bondi/hot accretion

$$\dot{M}_{\rm BH} \lesssim 1/3\,\dot{M}_{\rm Bondi}$$



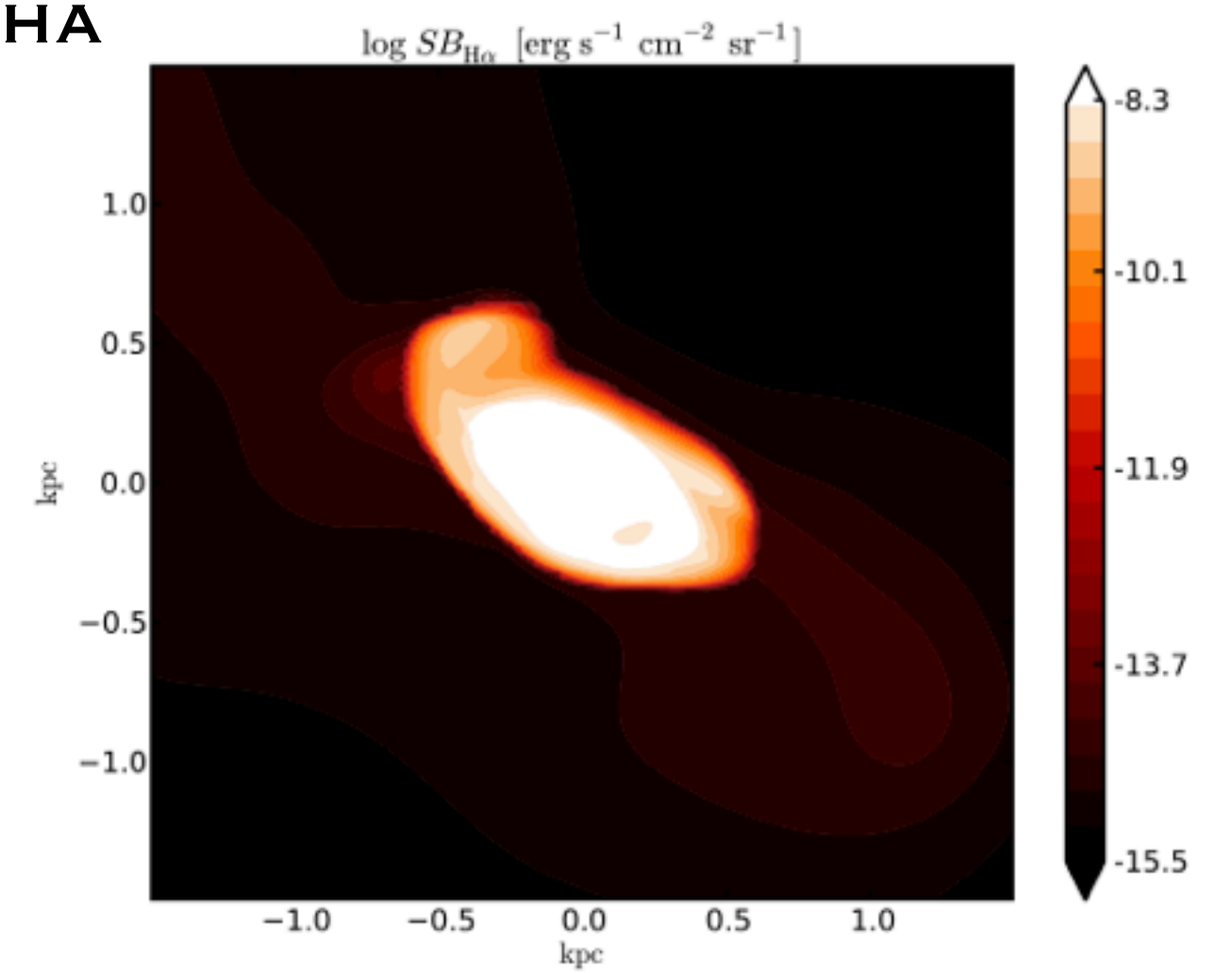
e.g. NGC 4649 (Humphrey et al. 2008)
NGC 1332 (Humphrey et al. 2009)

HALPHA

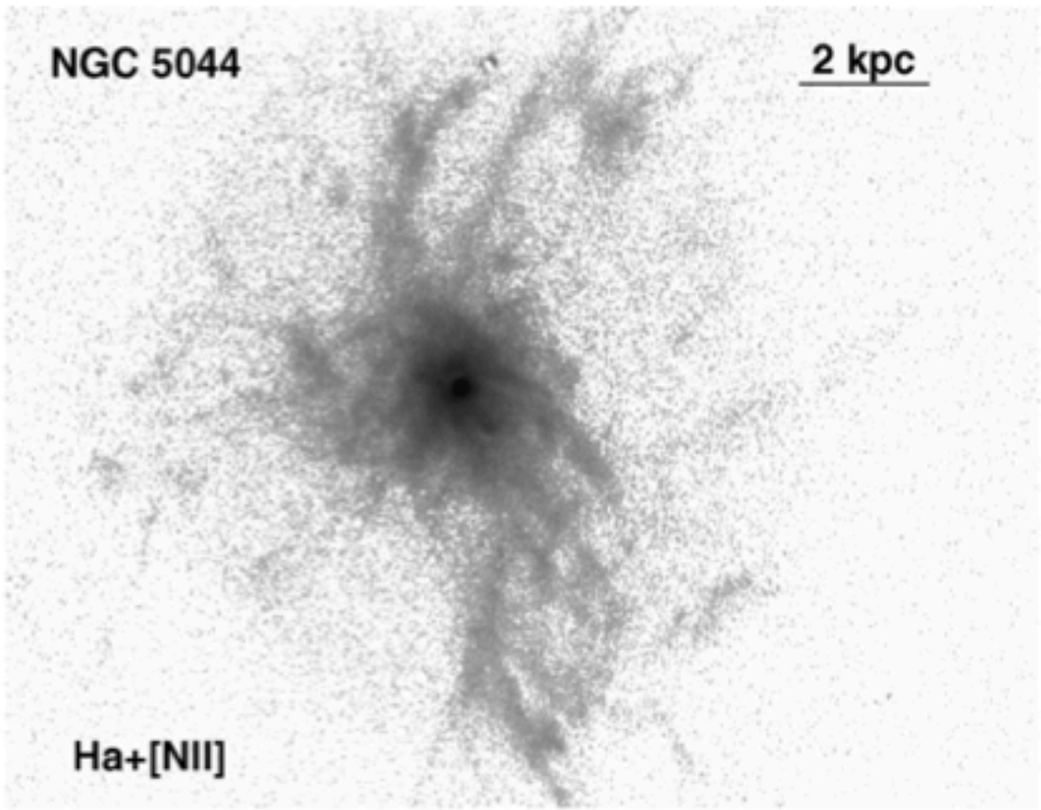


full CCA

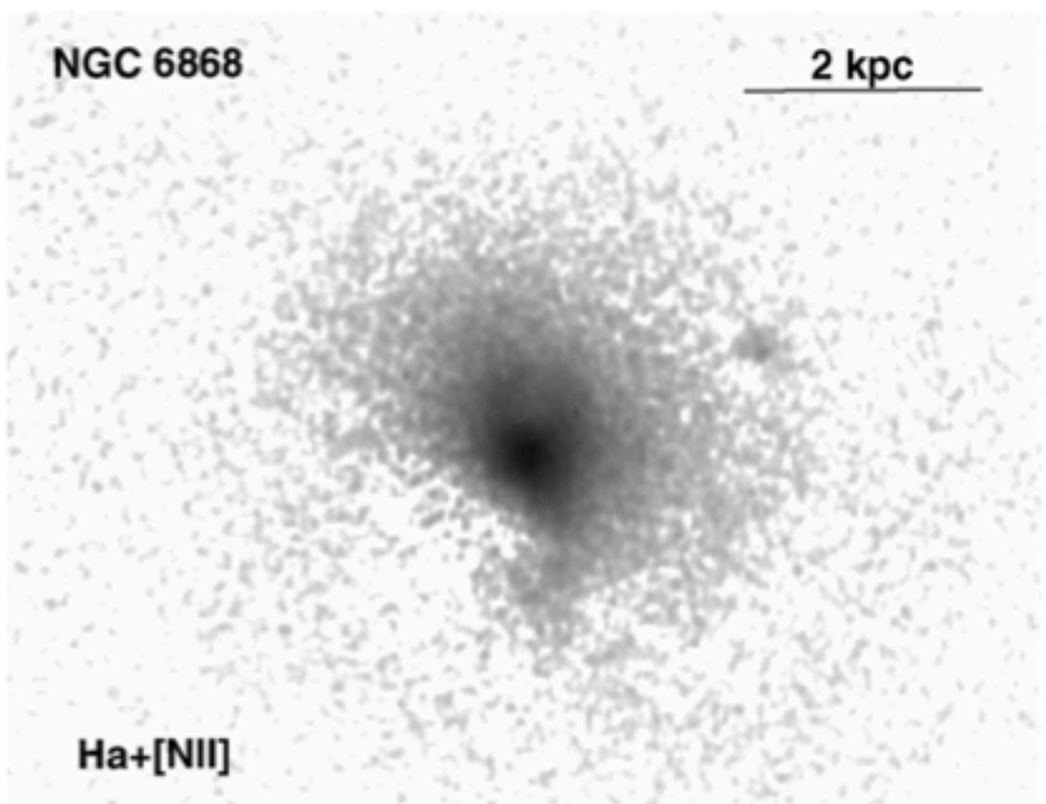
SIMS
MG+15



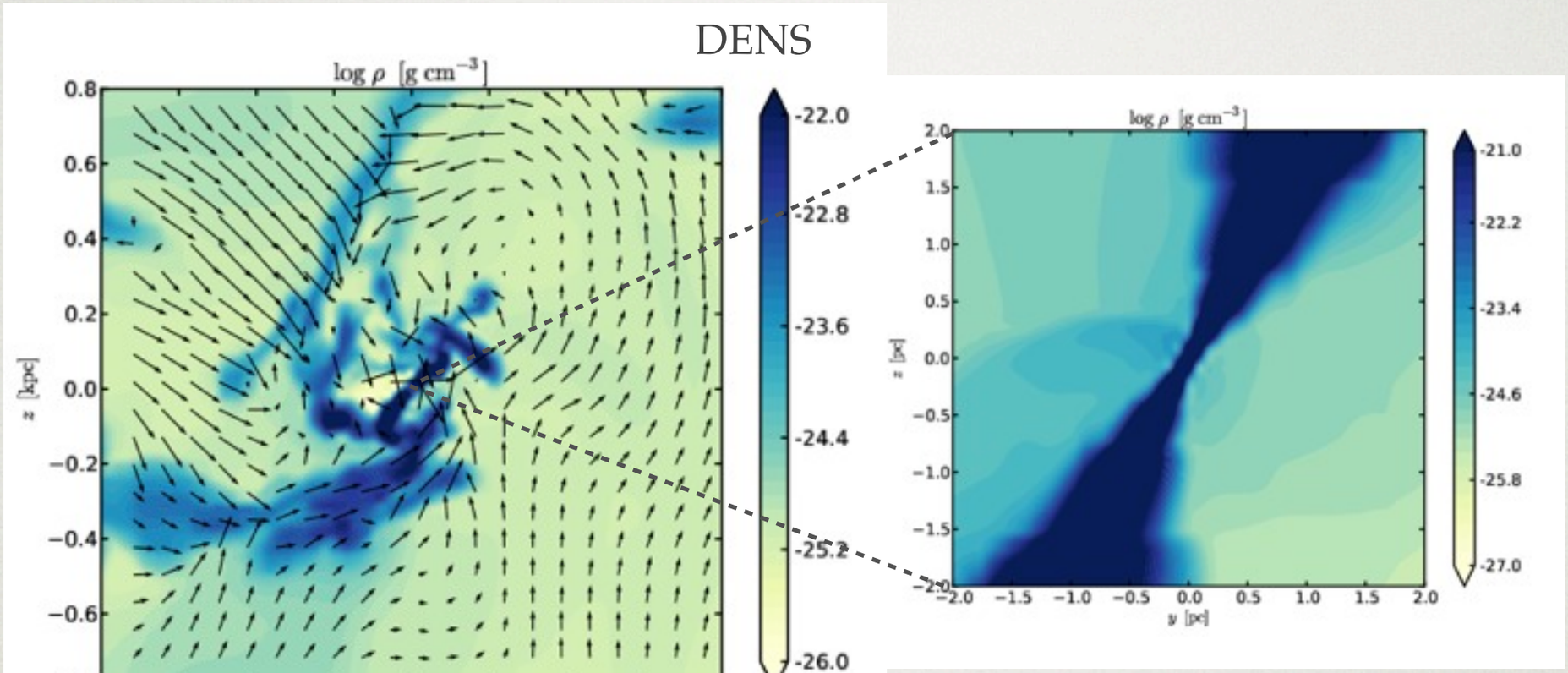
disc mode



SOAR DATA
Werner+14



“Raining on to black holes”



MG+13

- Highly clumpy & turbulent torus (key for AGN unification theory)
- Cold clouds can form the BLR/NLR & induce rapid variability in $L_{\rm AGN}$
- Tight **symbiosis** between the BH and the <u>whole</u> galaxy: $M_{\rm BH} \propto M_{\rm cold} \propto M_*$
- Fast communication time BH - galaxy and boosted accretion $\dot{M}_{\rm BH} \sim \dot{M}_{\rm cool}$:

CCA as main driver of AGN feedback

AGN feedback Cycle

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

↓

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

↓

thermal instabilities

↓

cold clumps

↓

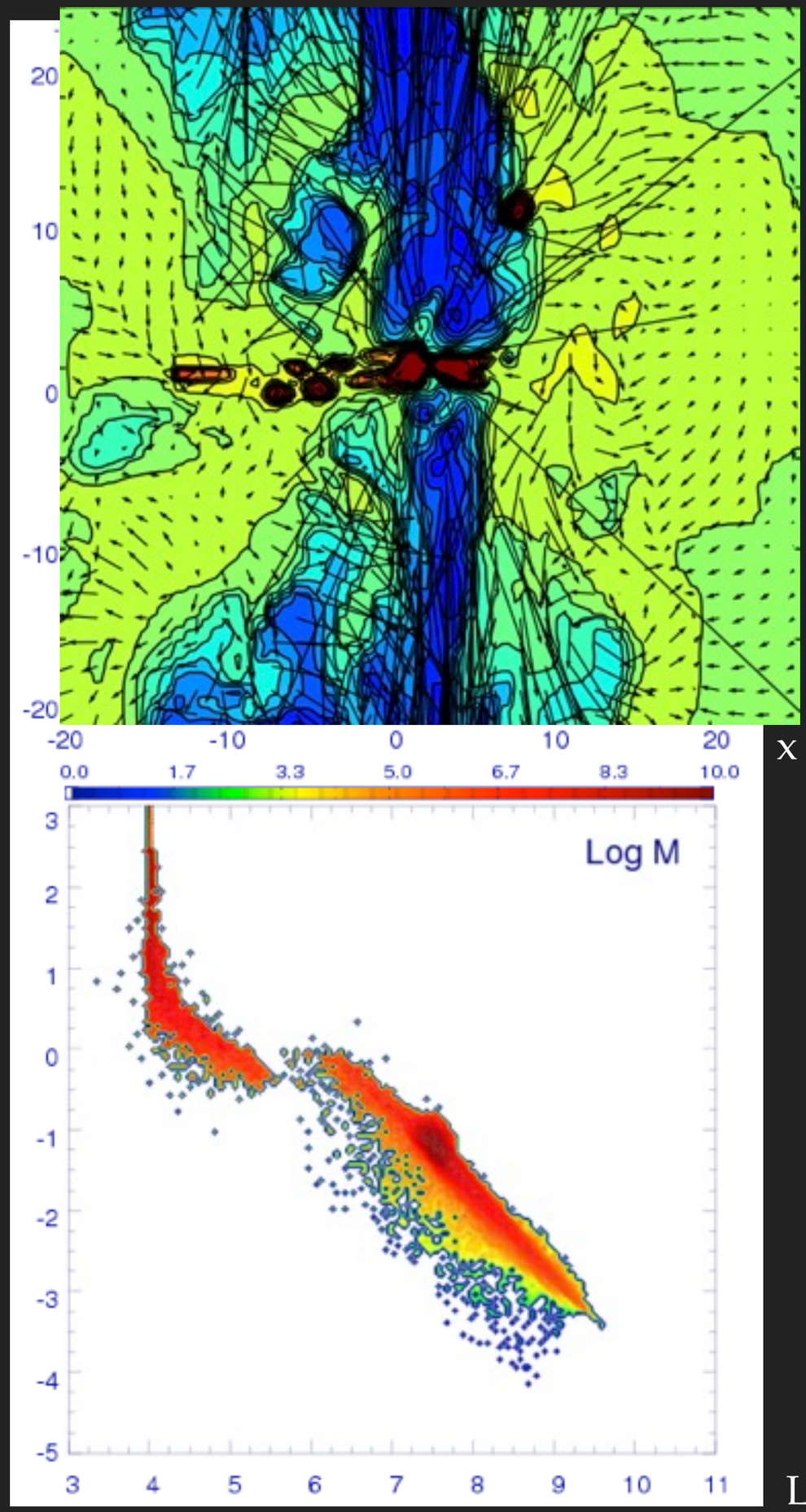
feed SMBH

↓

feedback boosted

↓

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



AGN OUTFLOWS WITH CCA FEEDBACK

galaxy group NGC 5044

MG+2012

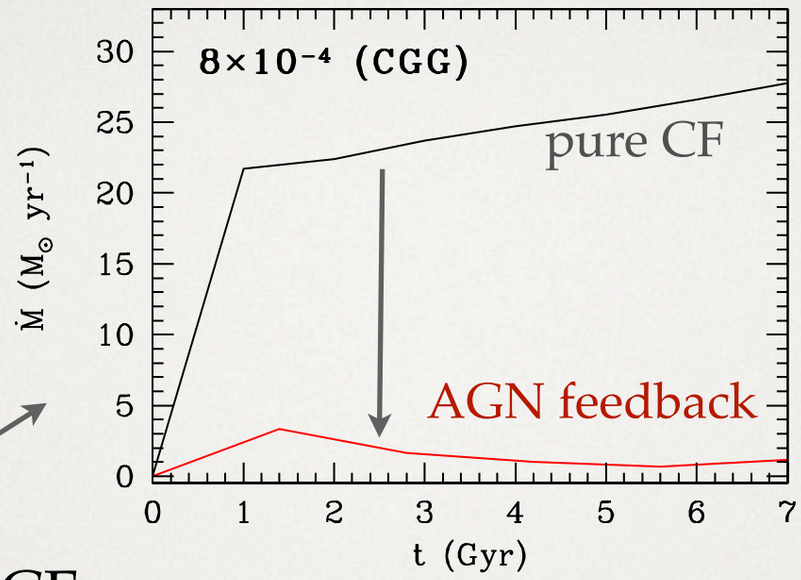
- Quenched cooling: < 5-10% CF

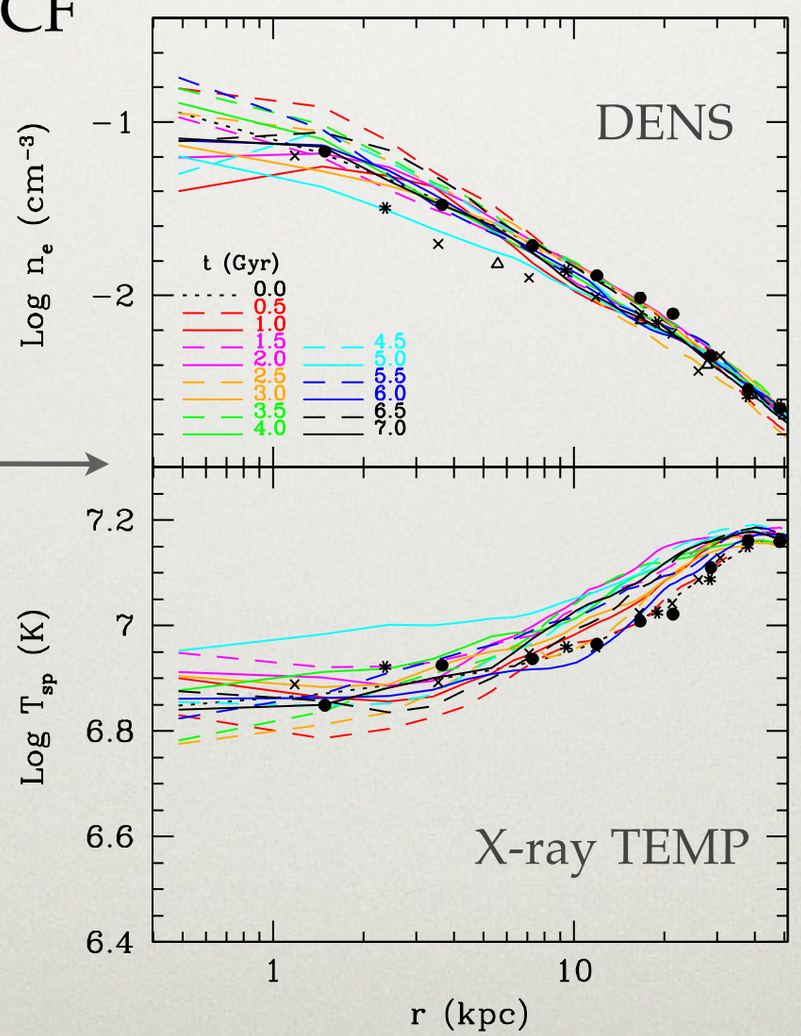
- Cool core preserved

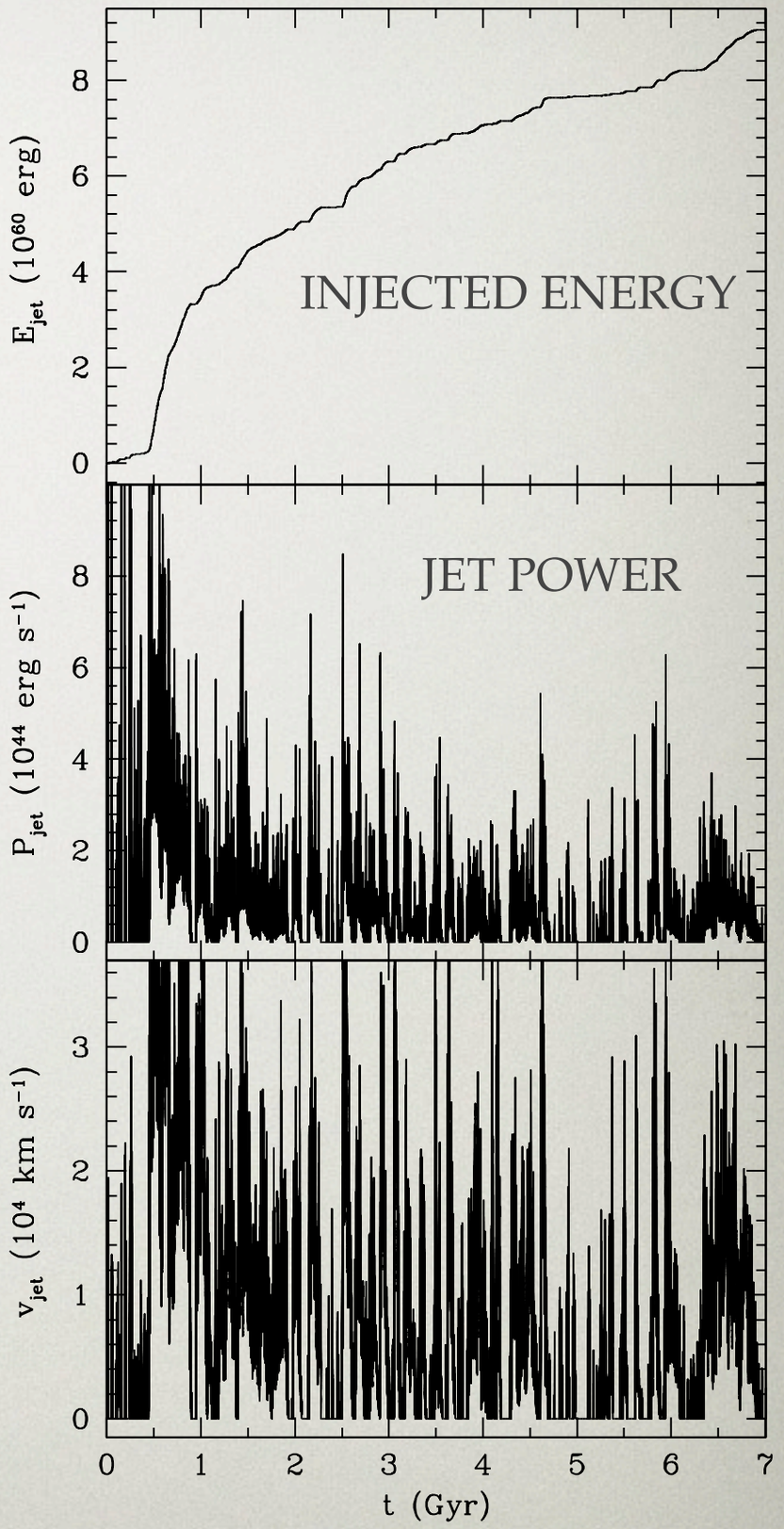
- Mechanical efficiencies:

  ~ 5×10^{-4} - 5×10^{-3}

  isolated galaxies ---> clusters



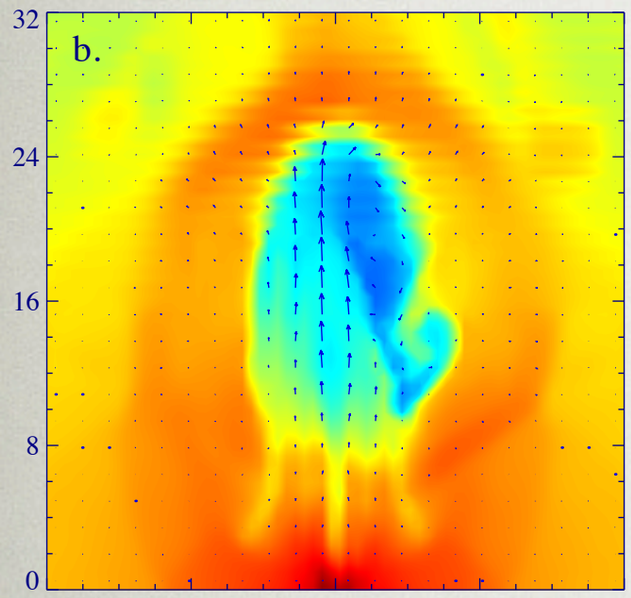




AGN IMPRINTS

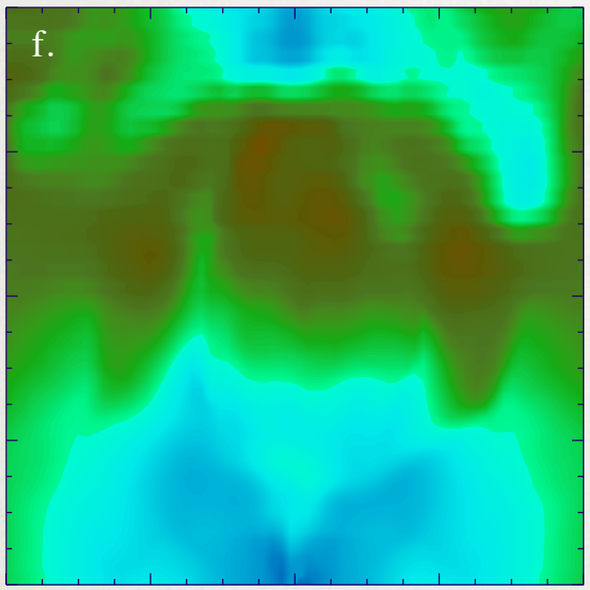
cocoon shocks

DENS



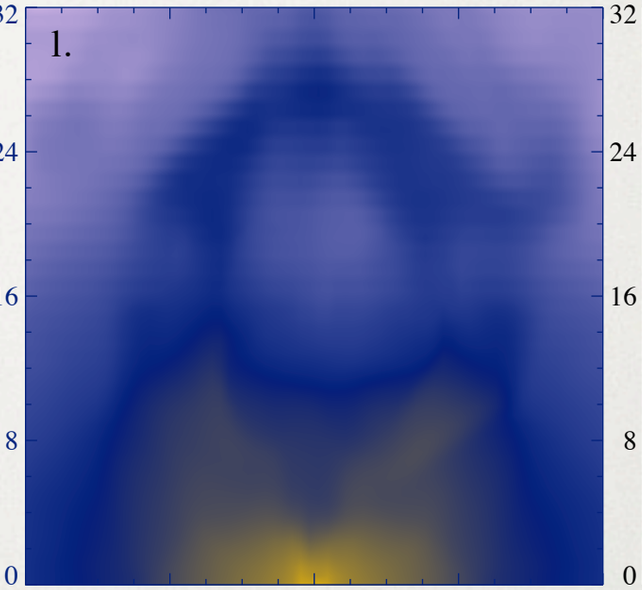
turbulence

X-ray TEMP



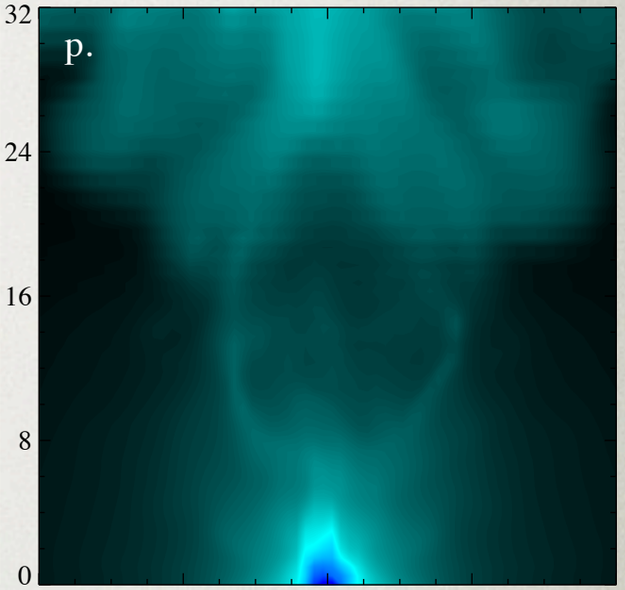
bubbles ~ 5-10 kpc

X-ray SB

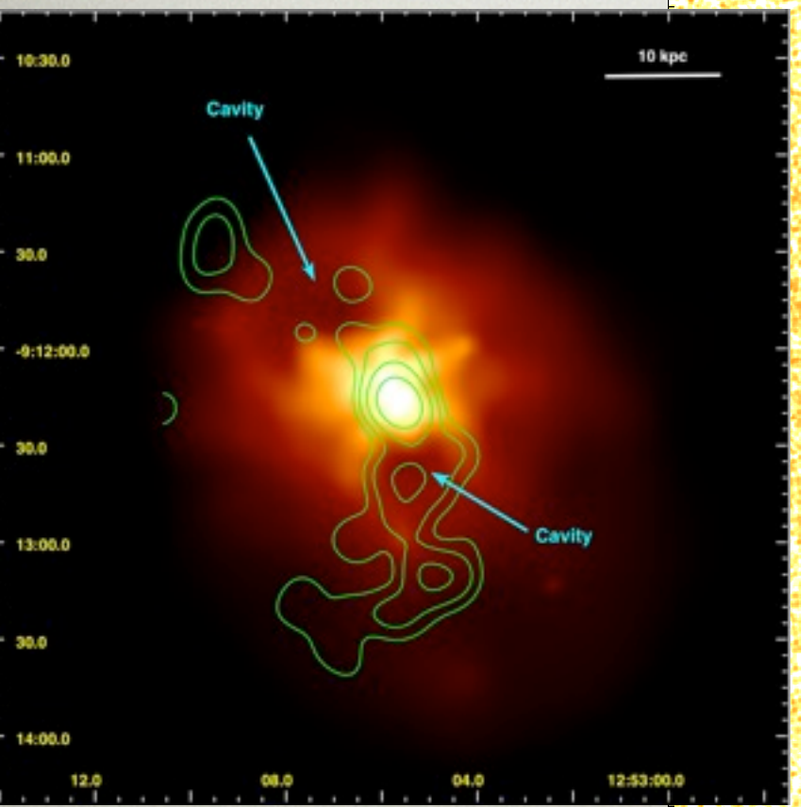


metal uplift

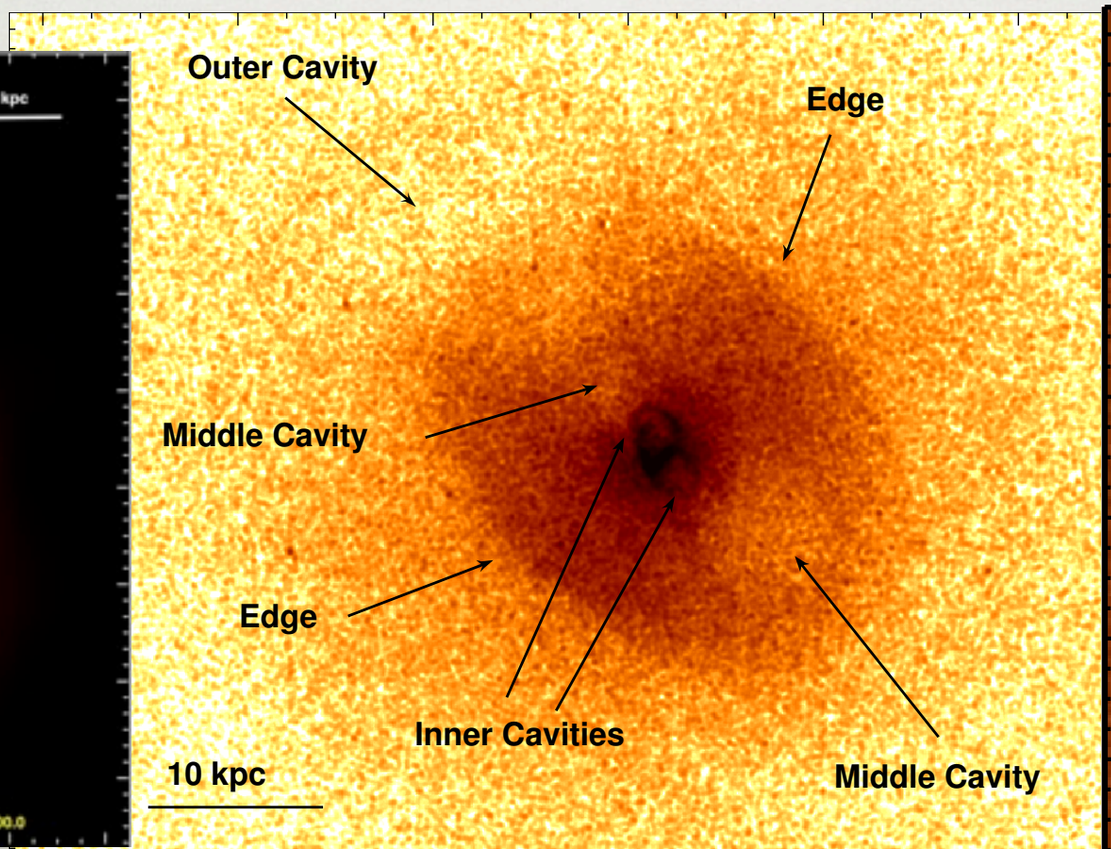
IRON



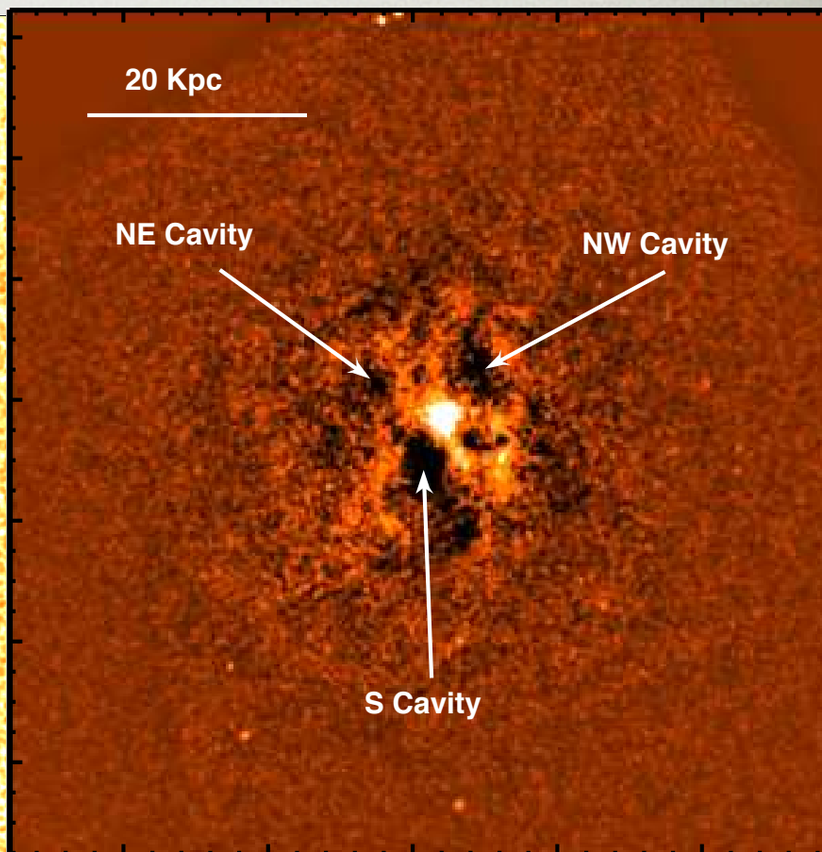
Gitti+2010 - HCG 62



Randall+2011 - NGC 5813

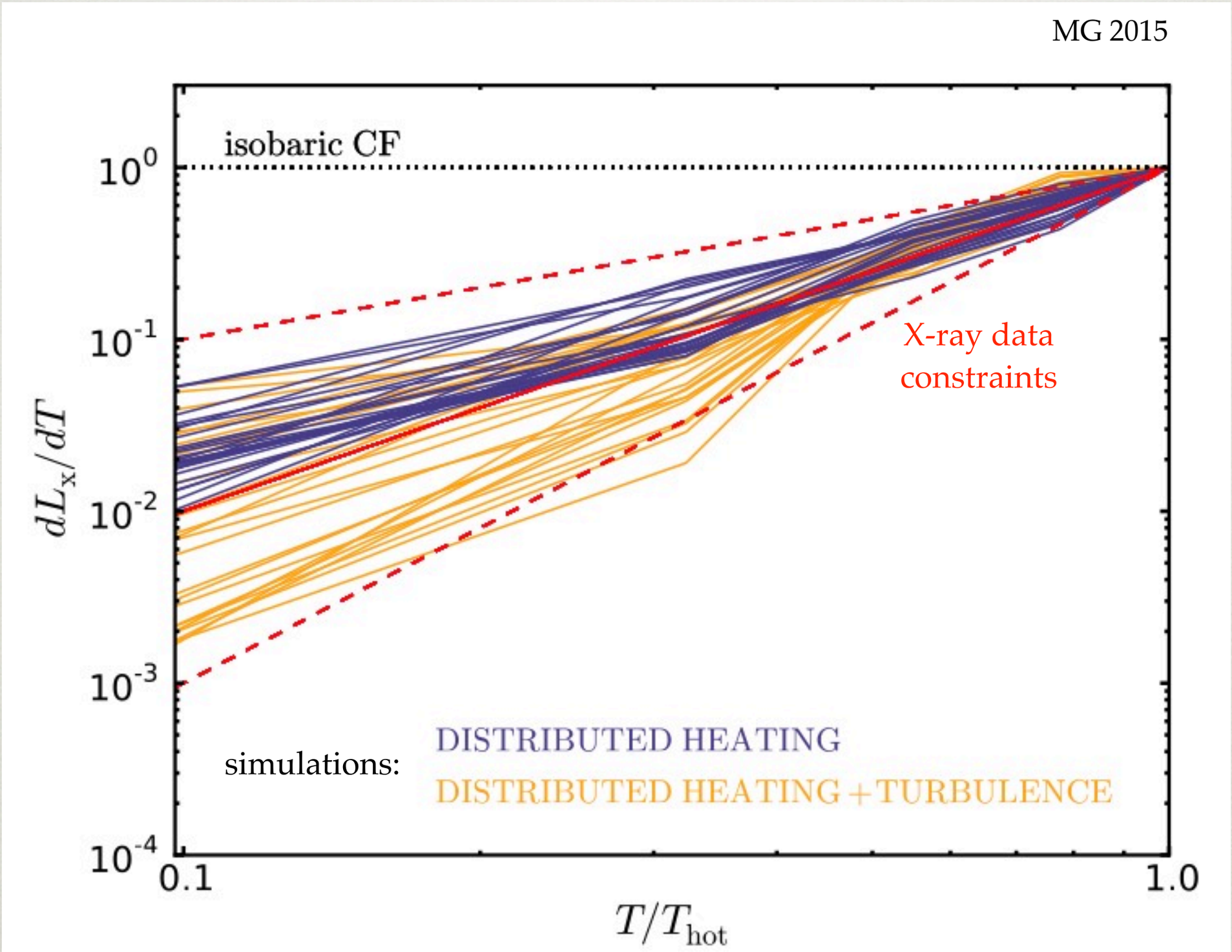


David+2009 - NGC 5044



QUENCHING THE SOFT X-RAY SPECTRUM

MG 2015



1. AGN outflows deposit relatively more heat in the inner cooler phase
2. turbulence becomes transonic in the cooler phase => stronger diffusion

SELF-REGULATED AGN FEEDBACK

MG+2009 --> 2015

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

↓

$t_{\rm cool}/t_{\rm ff} < 10$ ← subsonic turbulence ~ **100 km/s**

↓

extended TI → clumpy torus & filaments (< 10 kpc)

(obs.: McDonald et al. 2011,2012, Werner et al. 2013, Wong et al. 2014)

→ tight and fast symbiosis BH - $M_{\rm bulge}$

↓

chaotic collisions: $\mathrm{Ta_t} < 1$

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

↓

mechanical feedback → quench the cooling flow and SF

→ bubbles, shocks, metal uplift

↓

$\mathrm{Ta_t} > 1$ → residual cold disc: $\dot{M}_{\rm BH} \propto \mathrm{Ta_t}^{-1}$

(obs.: Young et al. 2011, Alatalo et al. 2013, Werner et al. 2013)

↓

$t_{\rm cool}/t_{\rm ff} >> 10$ → system overheated

(obs.: Humphrey et al. 2008, 2009)

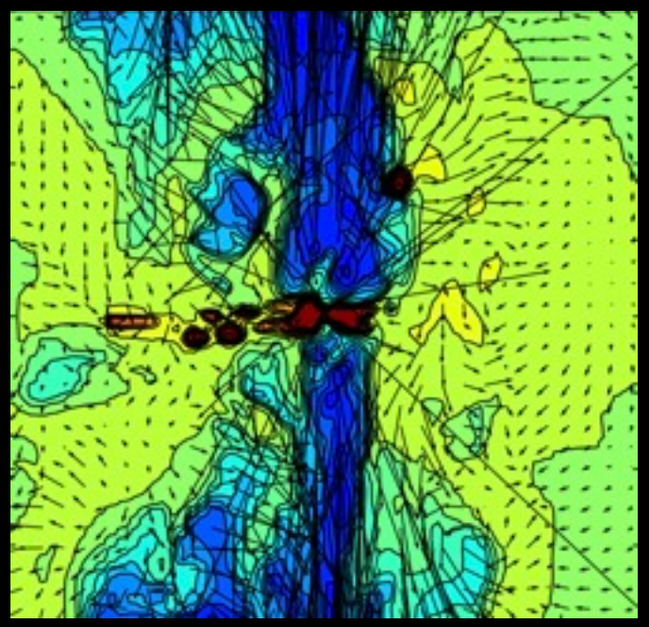
↓

$\dot{M}_{\rm BH} < \dot{M}_{\rm Bondi}$

↓

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

chaotic
COLD mode
(flat T_X profile)



disc
COLD mode

stifled
HOT mode
(cuspy T_X profile)