Black Hole Accretion & Feedback driven by Thermal Instability

Massimo Gaspari

Max-Planck Institute for Astrophysics

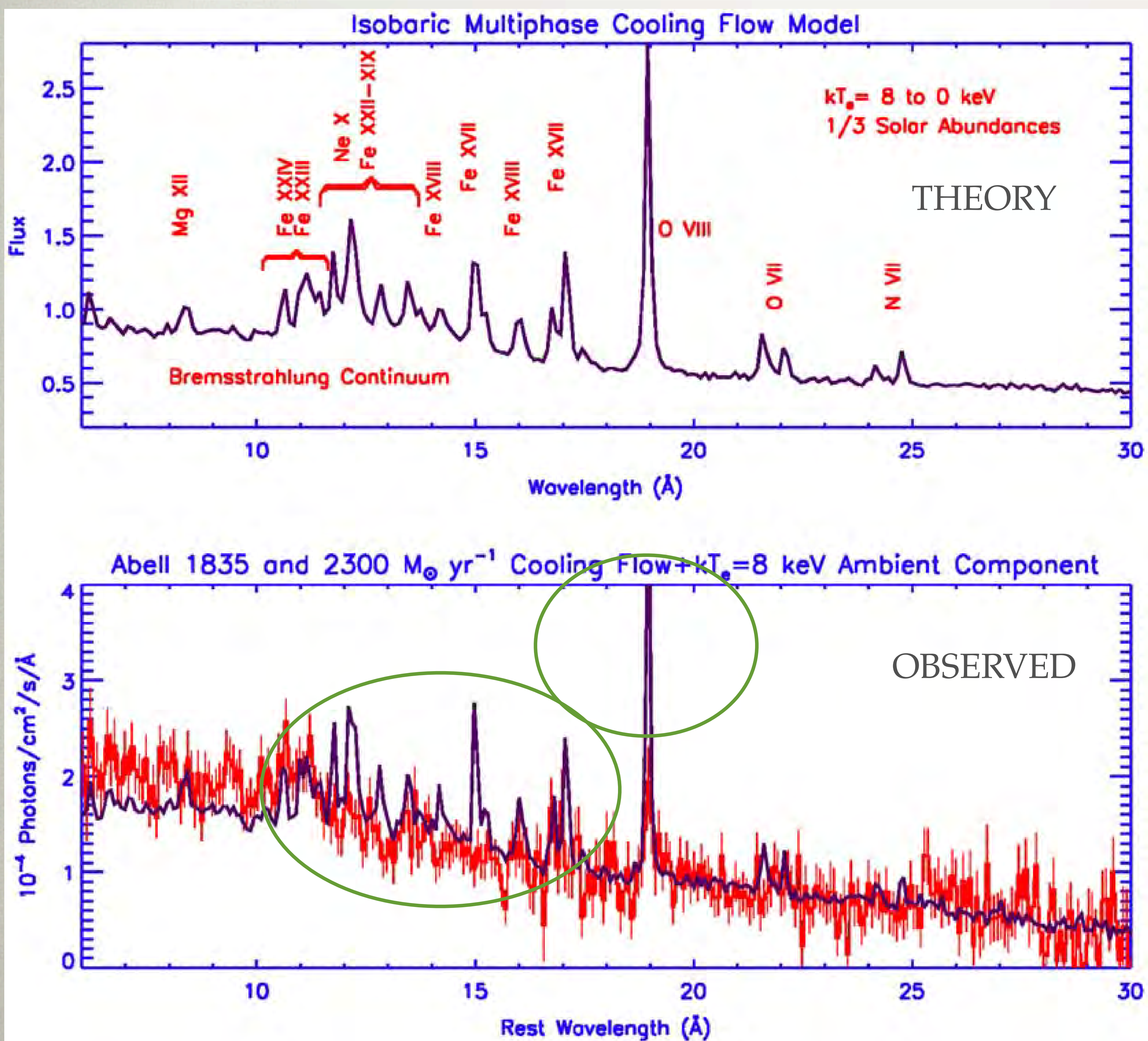
Collaborators - M. Ruszkowski, P. Oh , E. Churazov, F. Brighenti, S. Ettori, P. Sharma, P. Temi

1.

AVOID OVERCOOLING & OVERHEATING

(FOR SEVERAL GYR)

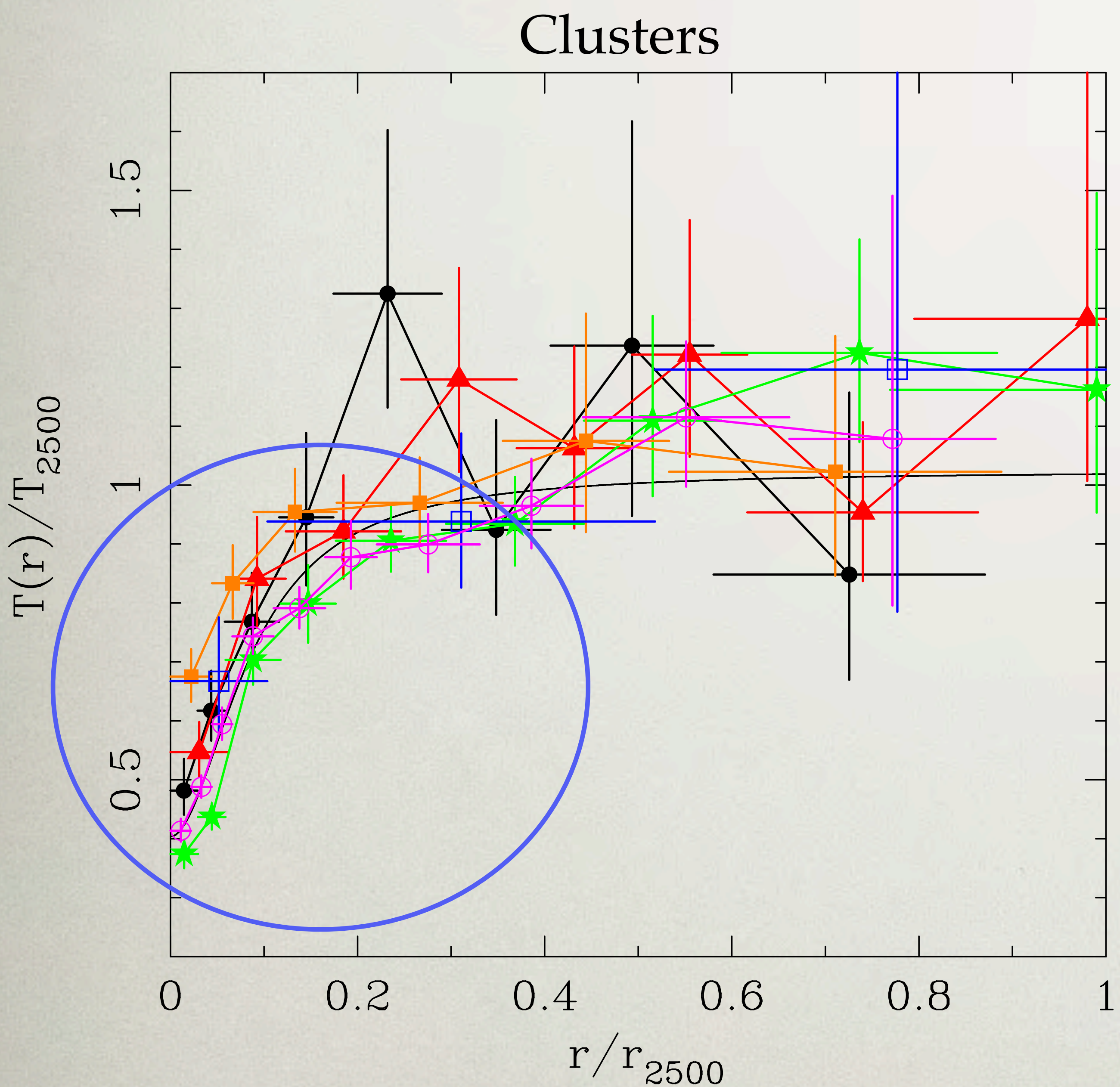
Quenching Cooling Flows



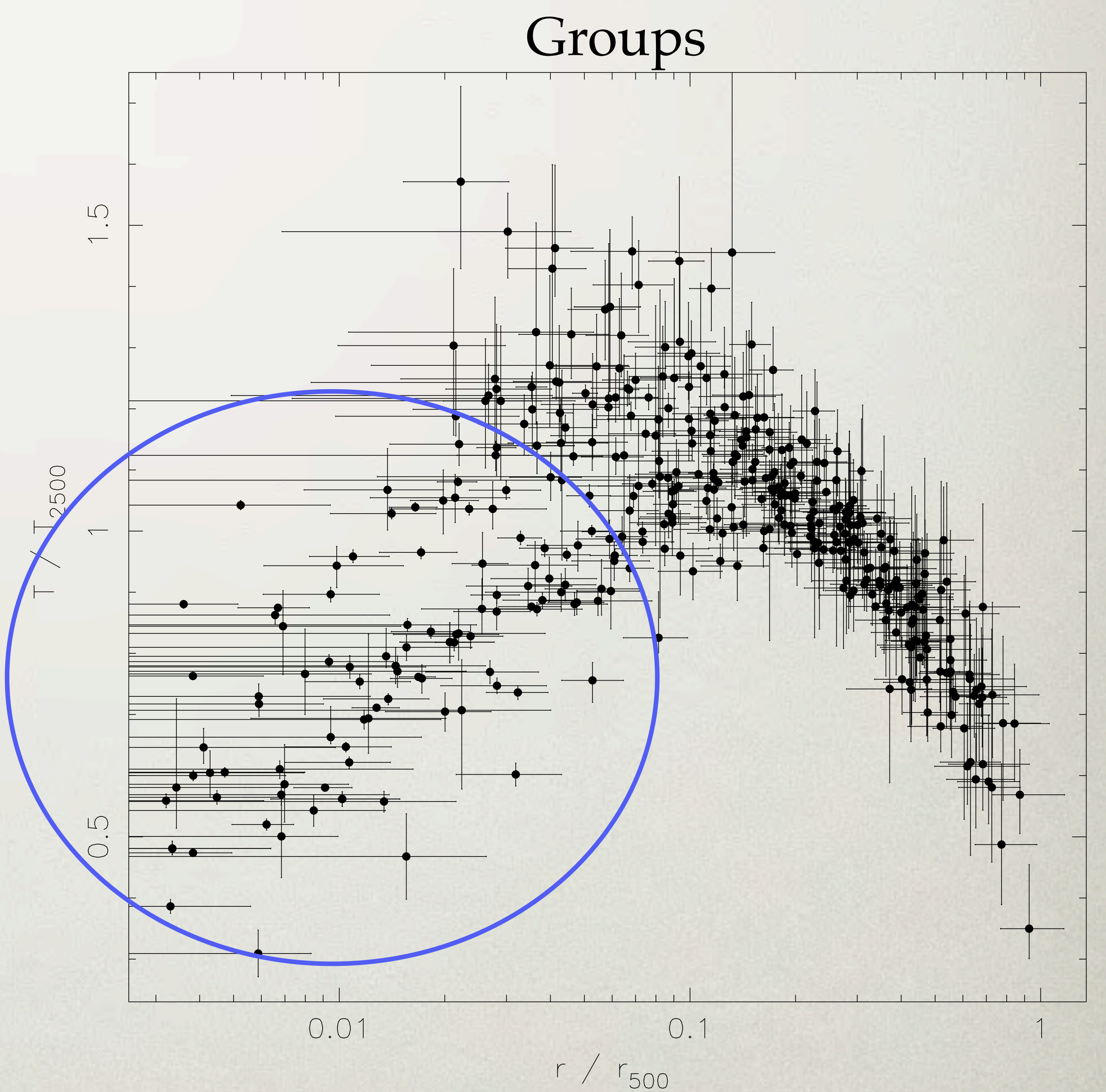
$$\dot{M}_{\rm real} \sim 1 - 10\% \ \dot{M}_{\rm CF}$$

XMM-RGS
Peterson+2001,2003,2006

Cool Core Survival



Allen+2001



Sun+2009

3D AMR LARGE-SCALE SIMULATIONS

see Gaspari+2011a,b, 2012a,b

Cluster $\rightarrow$ $M_{\rm vir} \approx 1 \times 10^{15}\ M_\odot$

Group $\rightarrow$ $M_{\rm vir} \approx 4 \times 10^{13}\ M_\odot$

Elliptical $\rightarrow$ $M_* \approx 3 \times 10^{11}\ M_\odot$

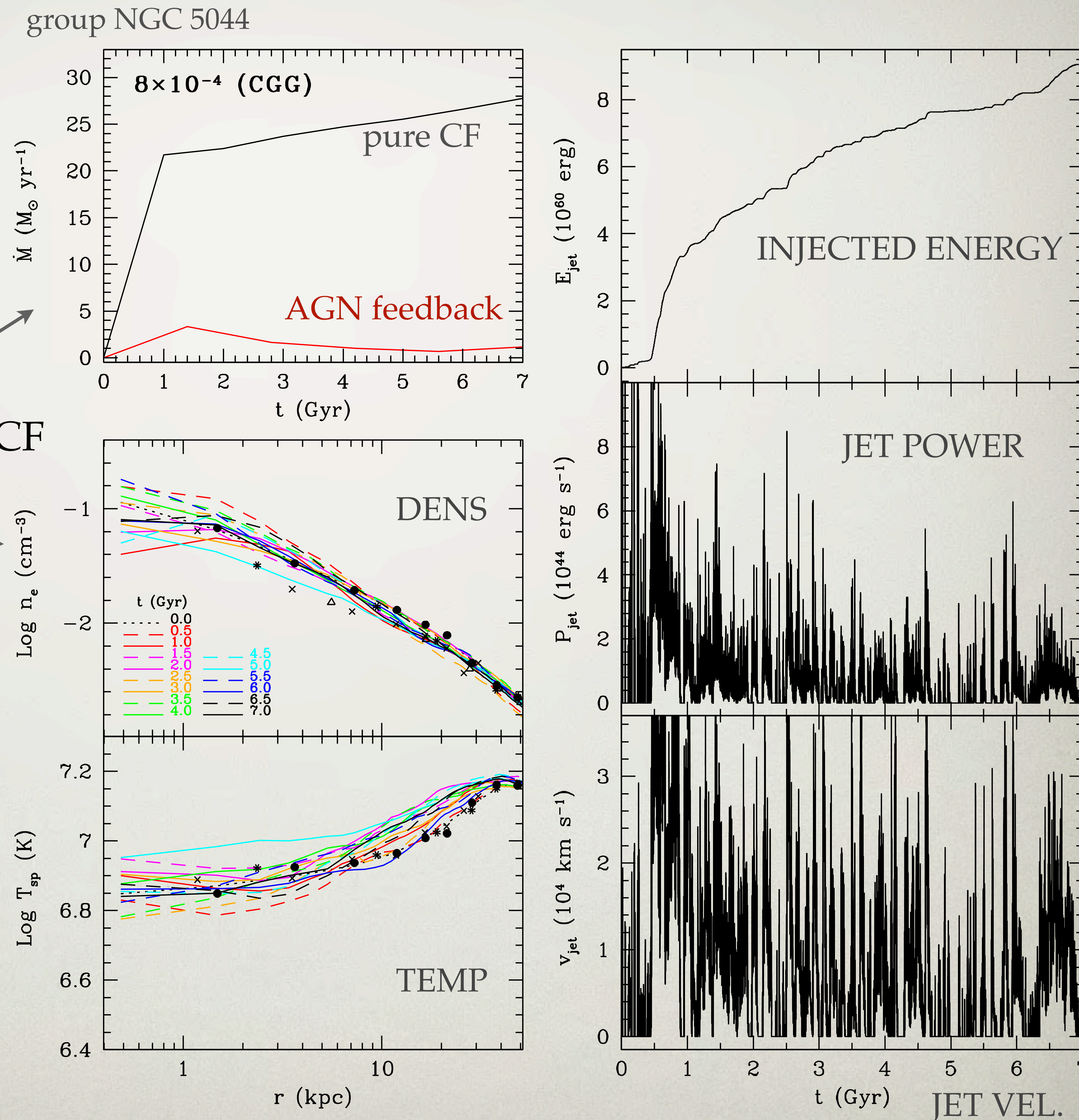
KEY PHYSICS - *FLASH*

- 3D gas dynamics: PPM (III order), max dx ~ 150 pc (range 10^4), $t_{\rm tot}$ ~ 7-10 Gyr
- gravity: dark matter NFW halo + BCG galaxy + SMBH
- radiative cooling: $\mathcal{L} = -n_e n_i \Lambda(T, Z)$
- SNe and stellar winds (heating + metal pollution)
- **AGN feedback: mechanical outflows/jets** (fiducial) or thermal blast (inconsistent)
- **Self-regulation: black hole cold accretion** (fiducial) or hot Bondi (inconsistent)

$$\frac{1}{2}\dot{m}_{\rm jet} v_{\rm jet}^2 = P_{\rm jet} = \epsilon\, \dot{M}_{\rm acc} c^2 \quad \longleftrightarrow \dot{M}_{\rm acc} \sim \dot{M}_{\rm cool}$$

OUTFLOW FEEDBACK SIMULATIONS

- Quenched cooling: < 5-10% CF
- Cool core preserved
- Power: ~ 10^{43} - 10^{46} erg s^{-1}
  Velocities: ~ 10^4 km s^{-1}
  Mass outflow: ~ few $M_\odot$ yr^{-1}
- Mechanical efficiencies:
  ~ $5\text{x}10^{-4}$ - $5\text{x}10^{-3}$
  (isolated galaxies - clusters)



Gaspari+2009, 2011a,b, 2012a,b

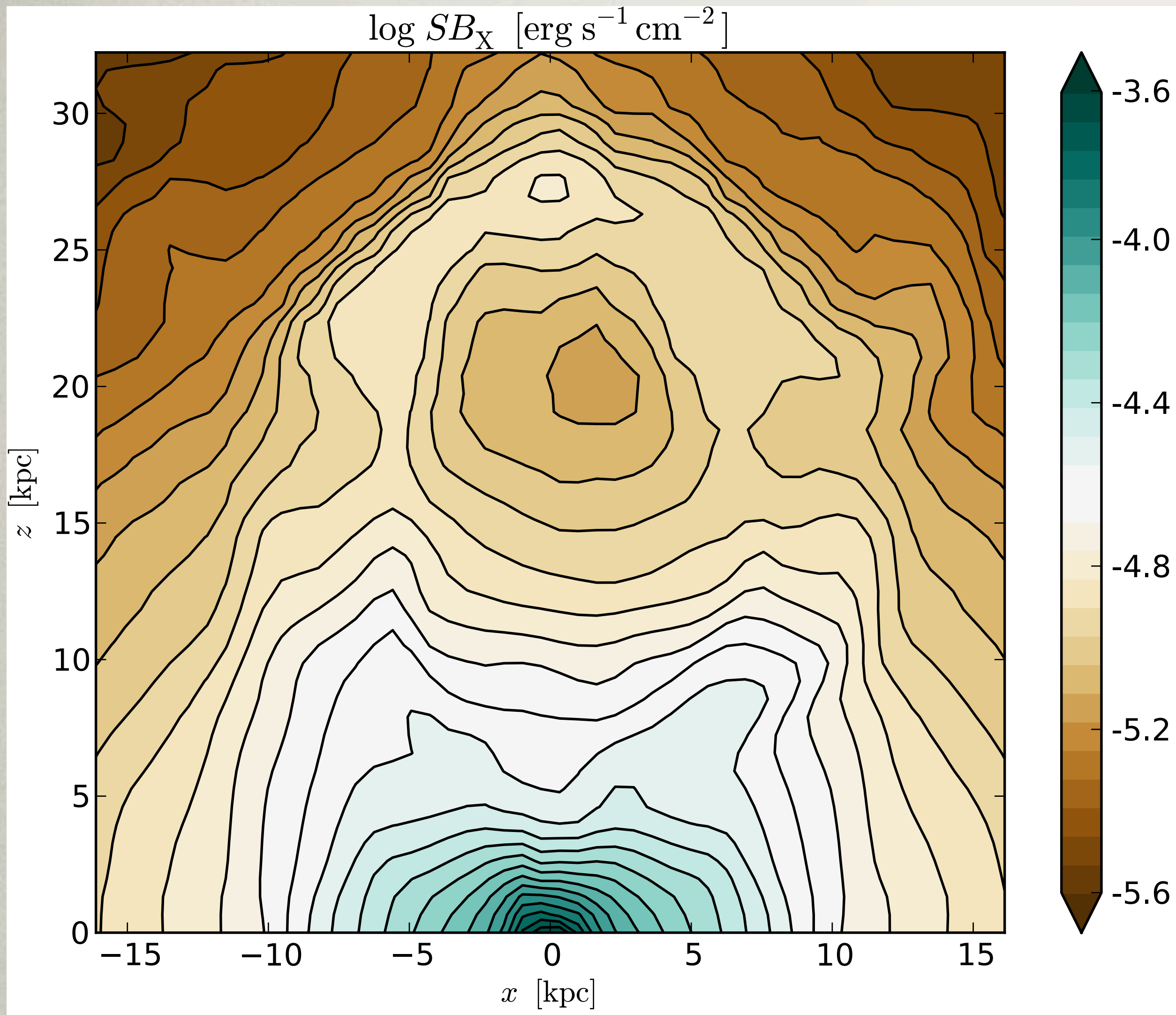
2.

Mechanical Outflows

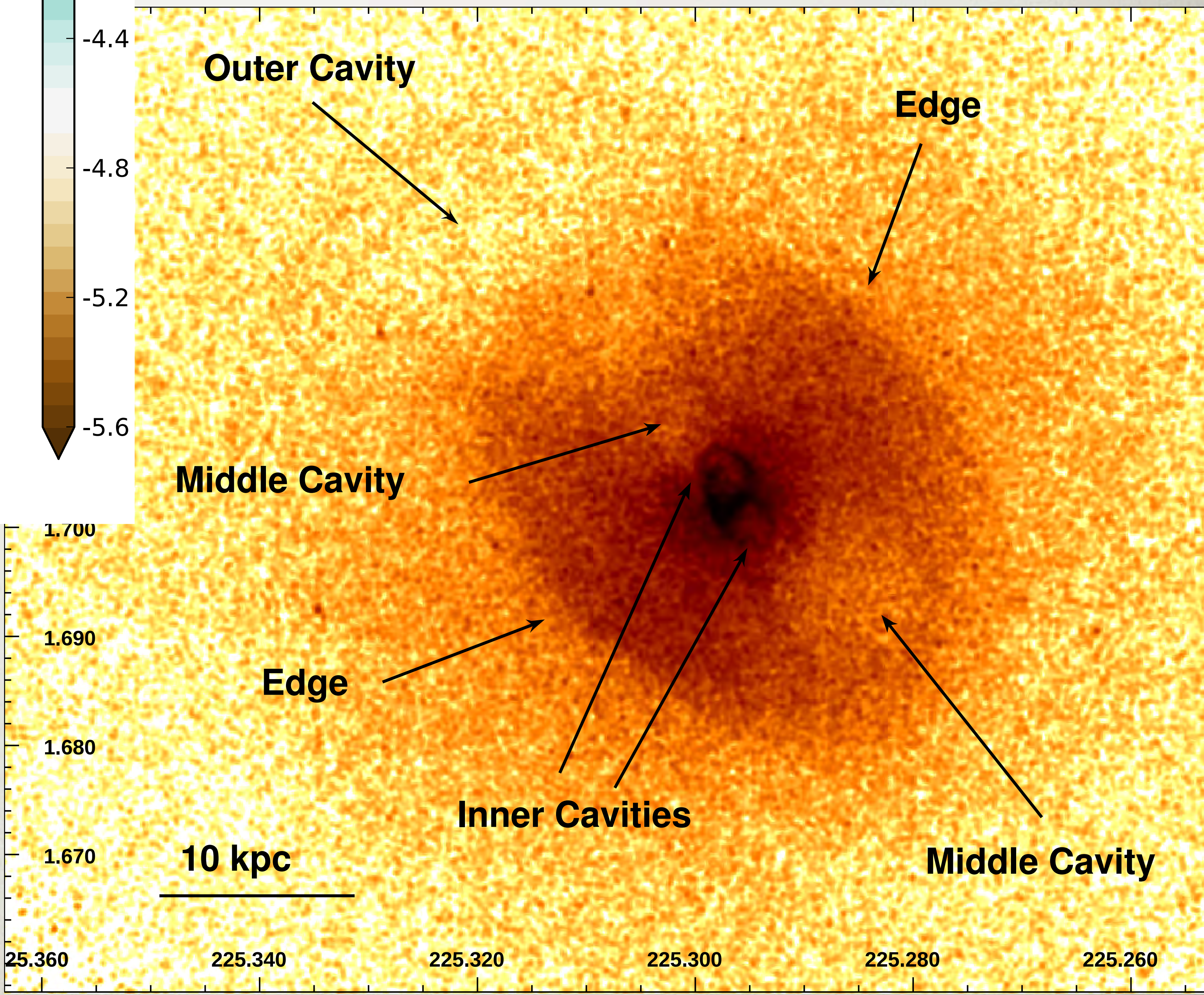
reproduce key

Feedback Imprints

Bubbles

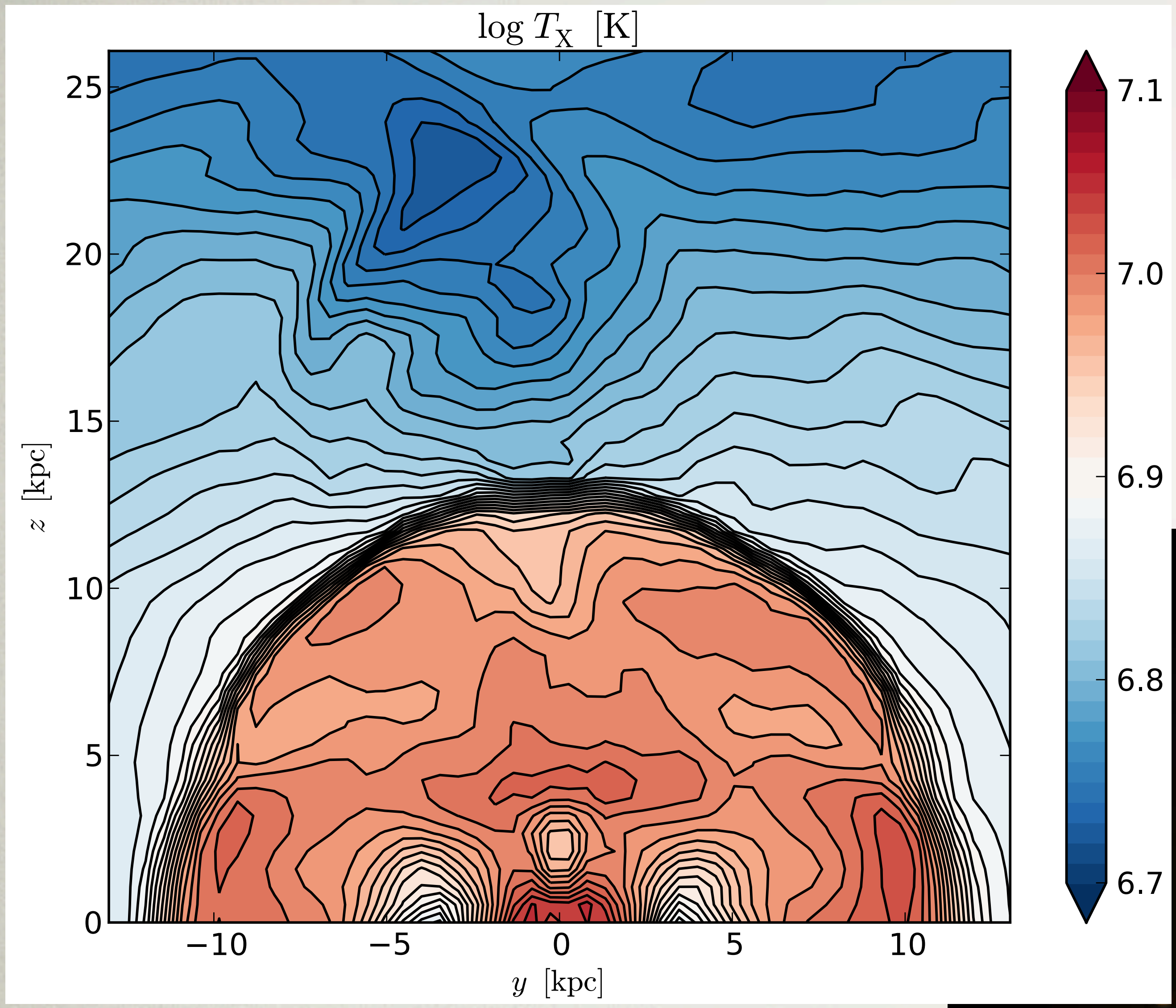


Gaspari+2011b



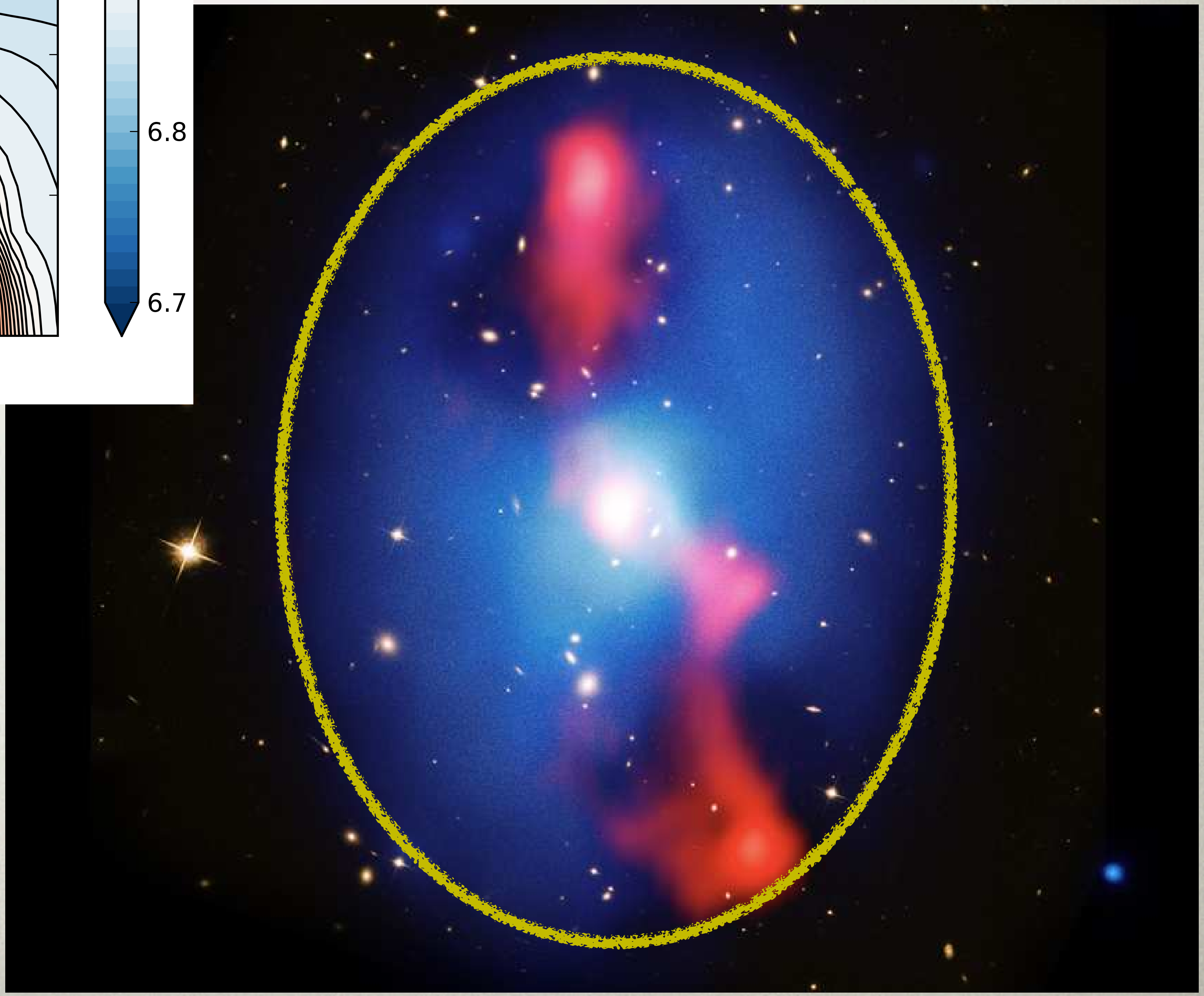
NGC 5813 - Randall+2011

Shocks

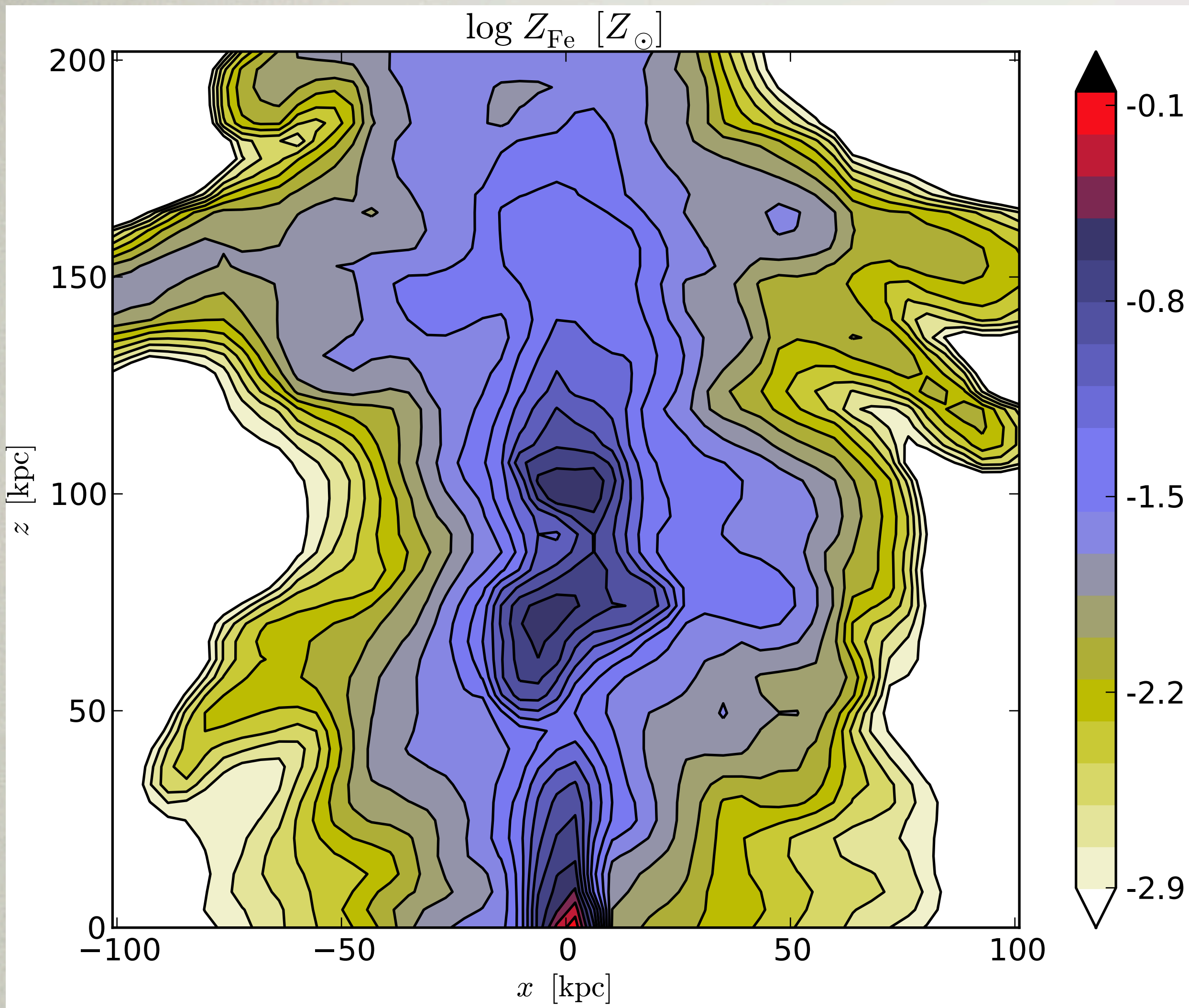


Gaspari+2012b

MS0735.6 cluster (McNamara+2005)

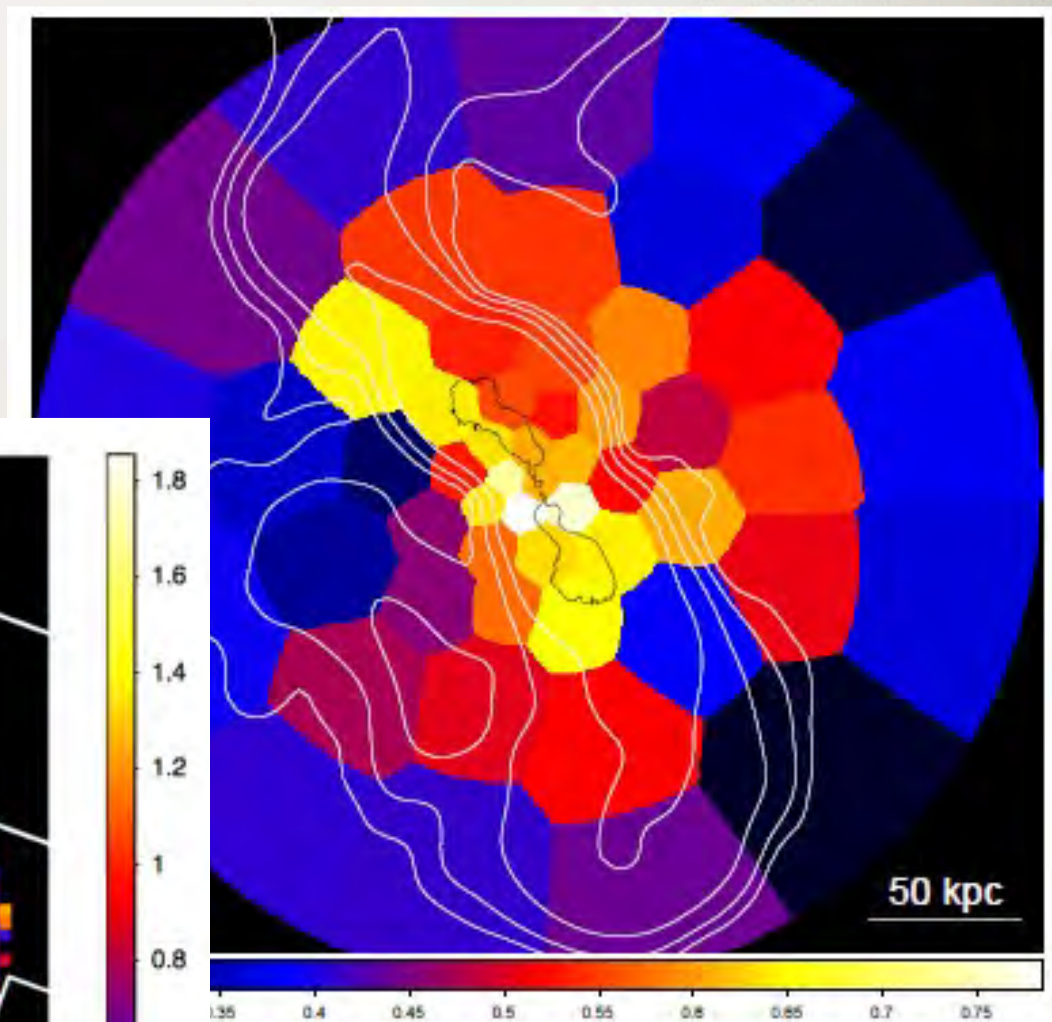


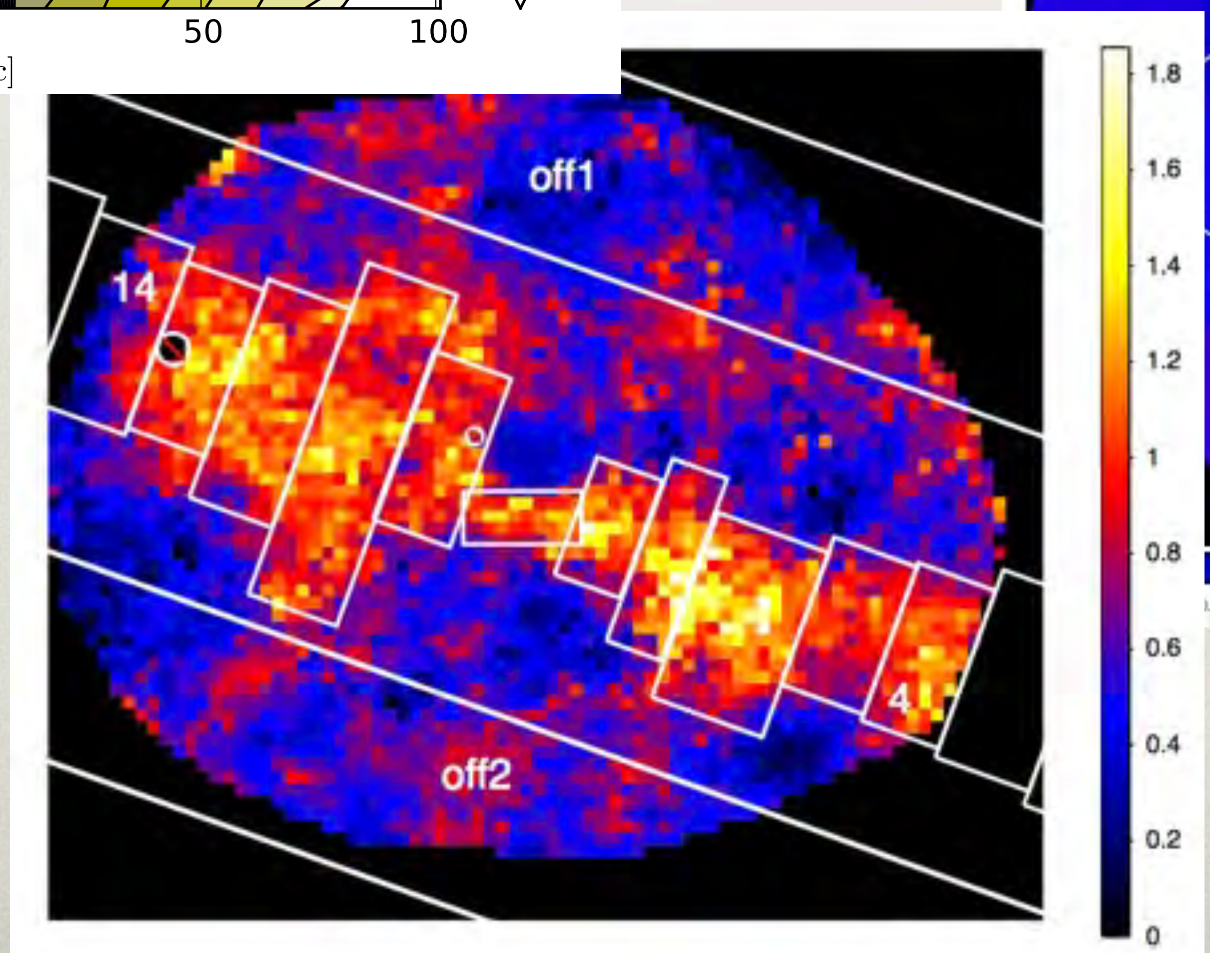
Metal Uplift



Gaspari+2012a

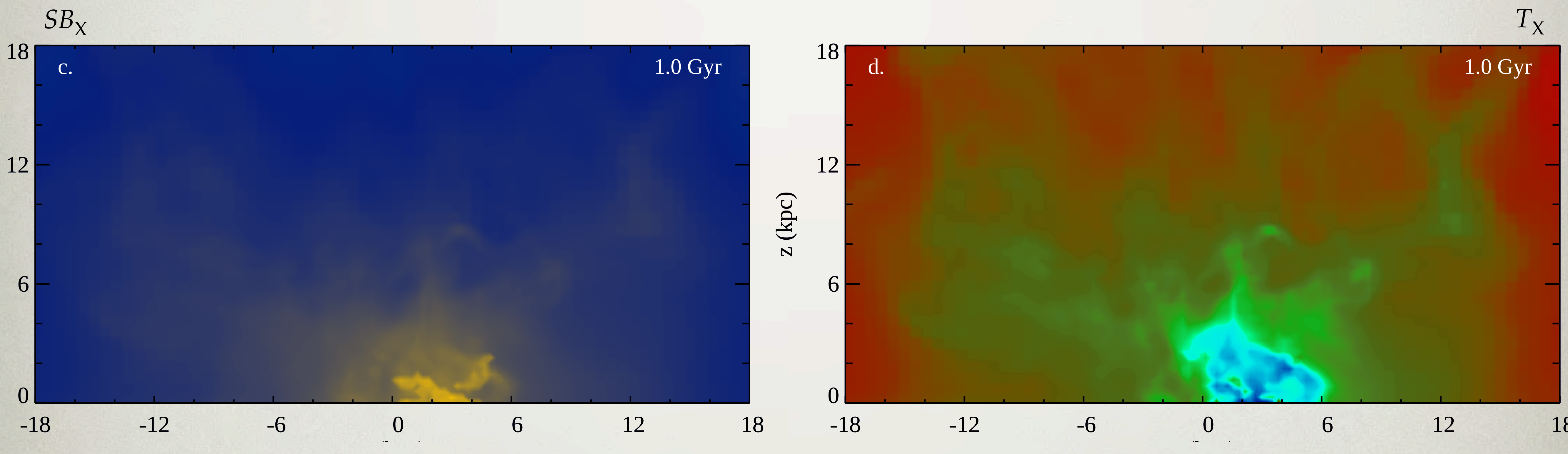
Hydra A - Kirkpatrick+2009, 2011





Zw 1742+3306
Ettori+2013, submitted

DRIVING TURBULENCE



Gaspari+2012b

$$\sigma_v \sim 200 - 400 \text{ km s}^{-1}$$

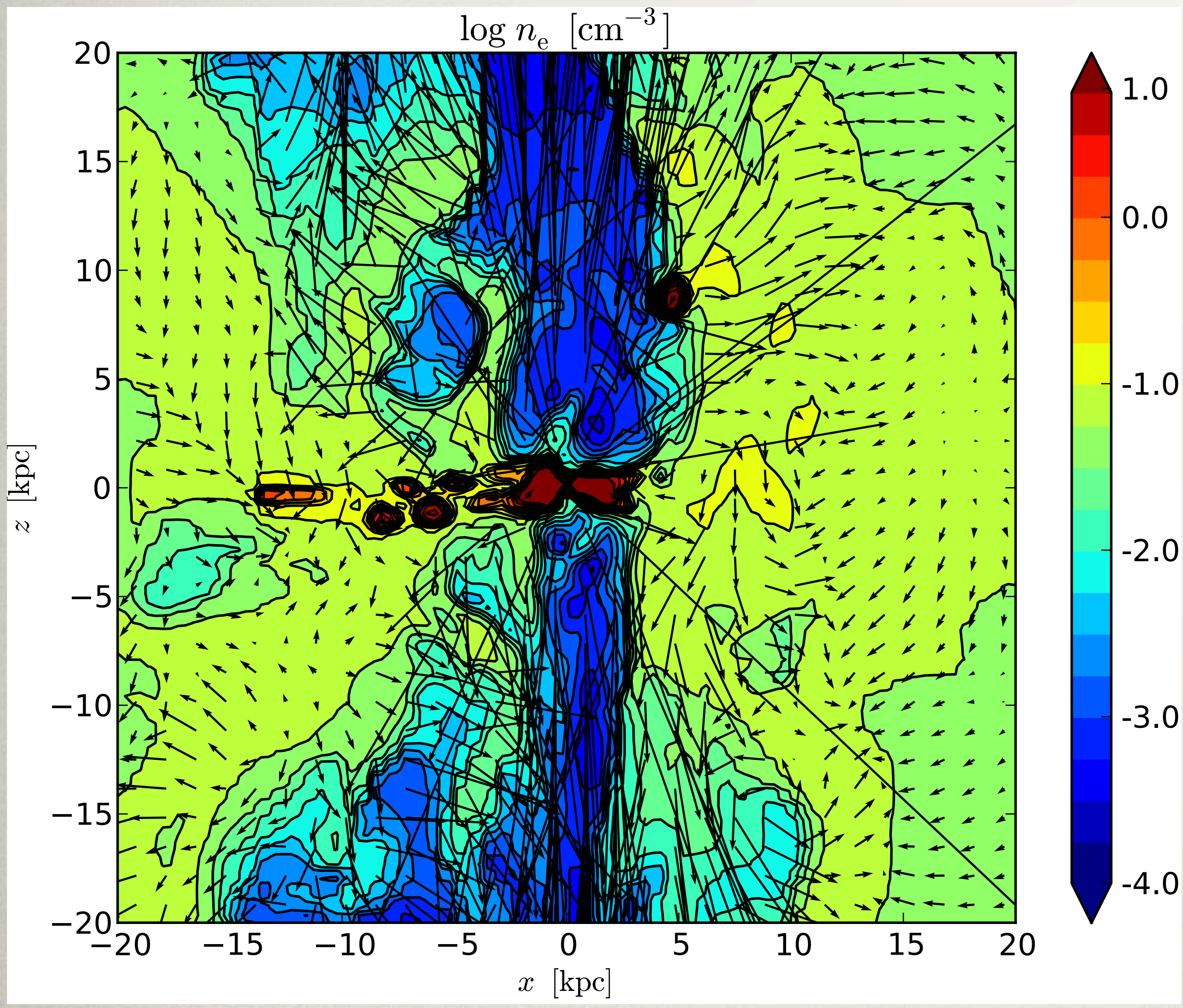
Very similar range in observations, e.g.:
de Plaa et al. 2012, Sanders & Fabian 2012

3.

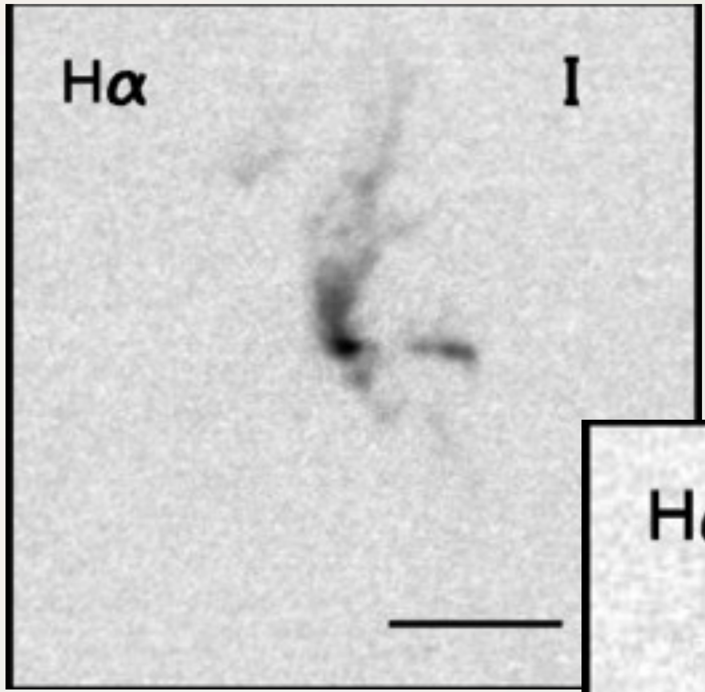
COLD GAS: BY-PRODUCT & FUEL

$$\dot{M}_{\rm BH} \sim \dot{M}_{\rm cool}$$

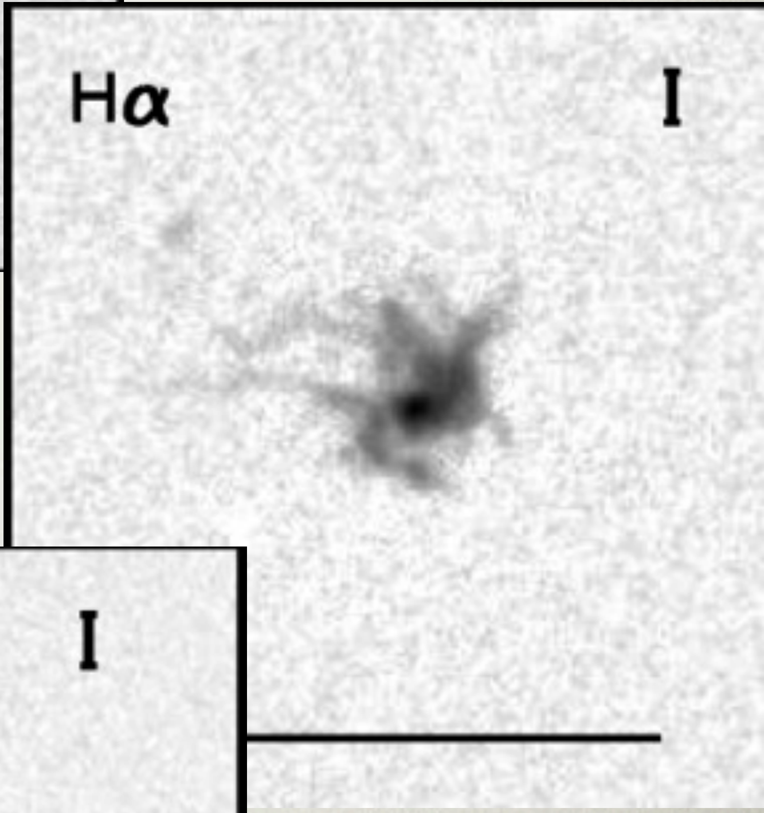
Residual Cold/Warm Gas



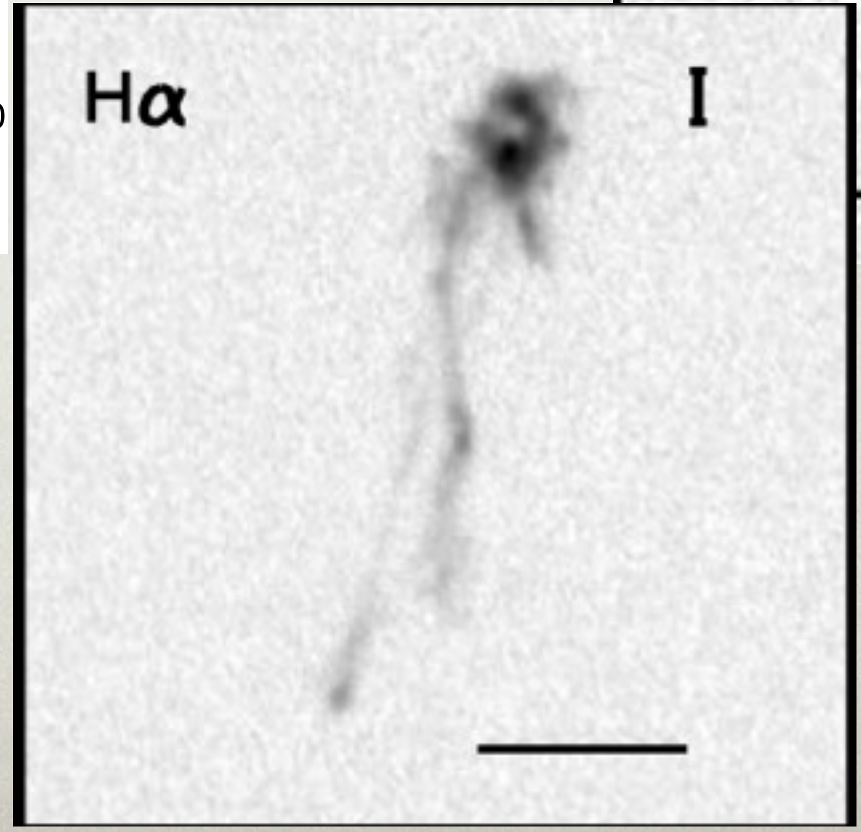
Gaspari+2012a



Sersic 159-03



A 0496



A 17954

Thermal Instability

SEE TALKS by Edge, McNamara, Werner

McDonald+2010,2011,2012

3D AMR small-scale simulations

Gaspari, Ruszkowski & Oh 2013

- **~10 million range**: 50 kpc ---> 20 R_S
- 3D gas dynamics: unsplit PPM (III order)
- gravity: dark matter halo (group) + BCG galaxy (NGC 5044) + SMBH (3x10^9 $M_\odot$)
- radiative cooling: $\mathcal{L} = -n_e n_i \Lambda(T, Z)$
- **turbulence: subsonic (**100s km s^{-1} **) - transonic** ---> spectral OU forcing
- **heating (global thermal equilibrium):** $\mathcal{H} \sim \langle \mathcal{L} \rangle$ (cf. McCourt+2012, Sharma+2012)
- Wide range of situations: **AGN feedback, SNe, mergers, galaxy motions, ...**

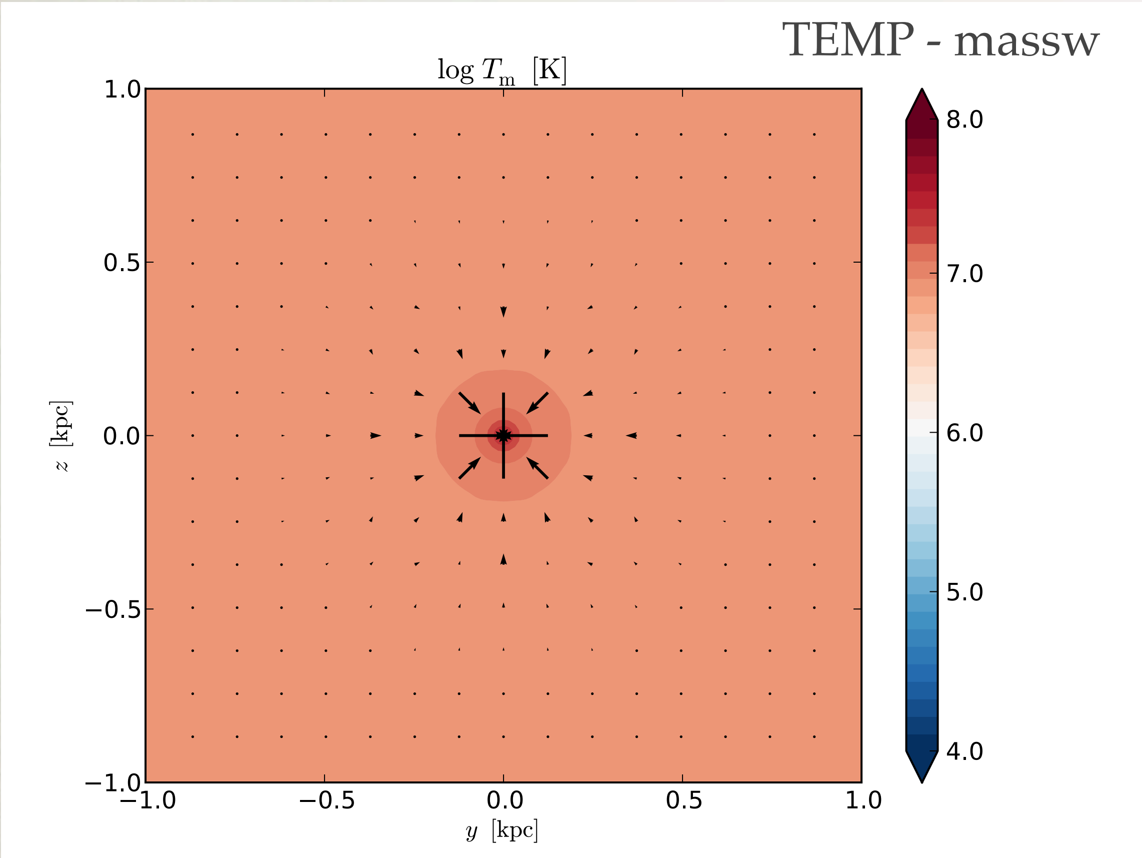
- future improvements: magnetic fields, cosmology, conduction

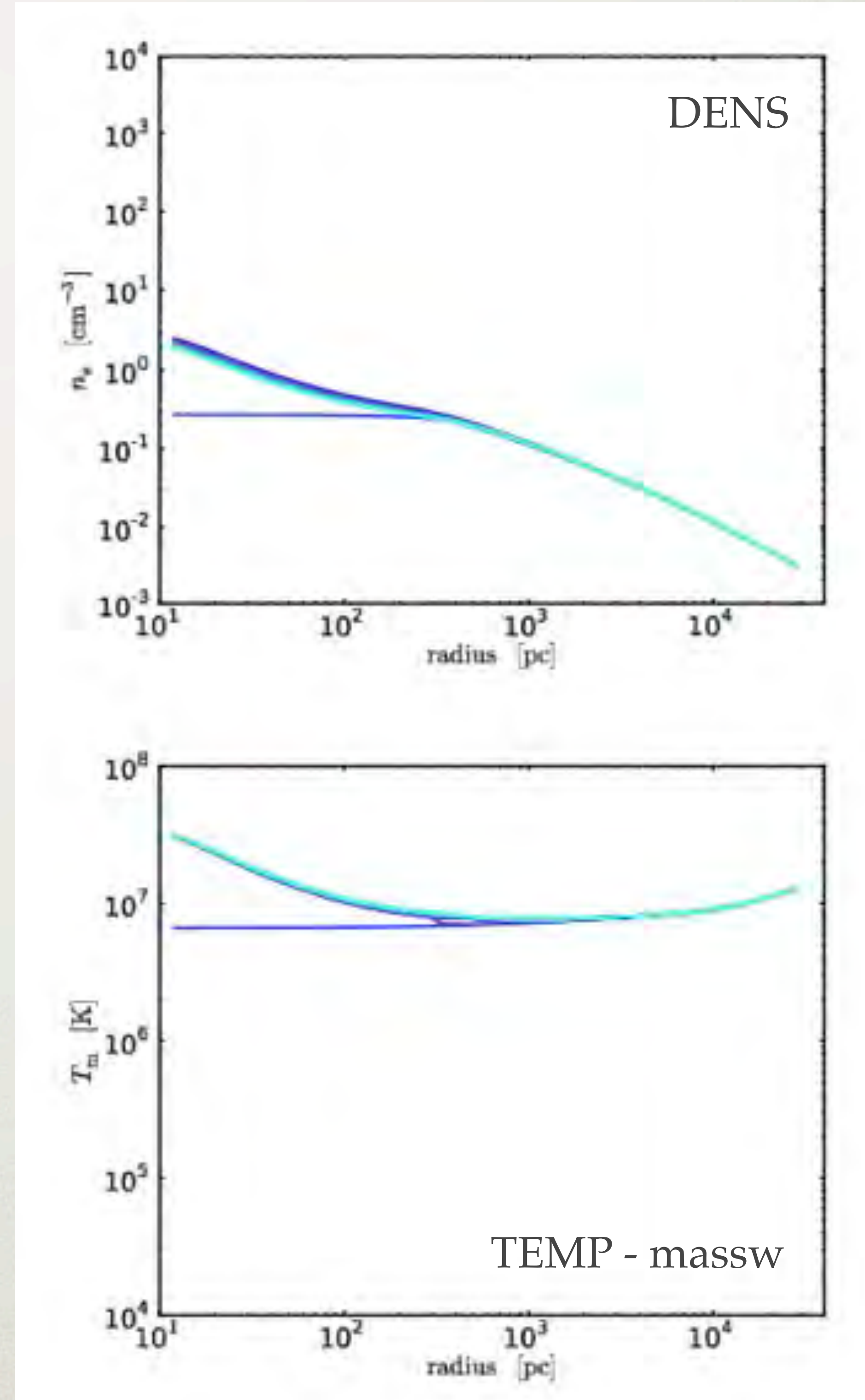
4.

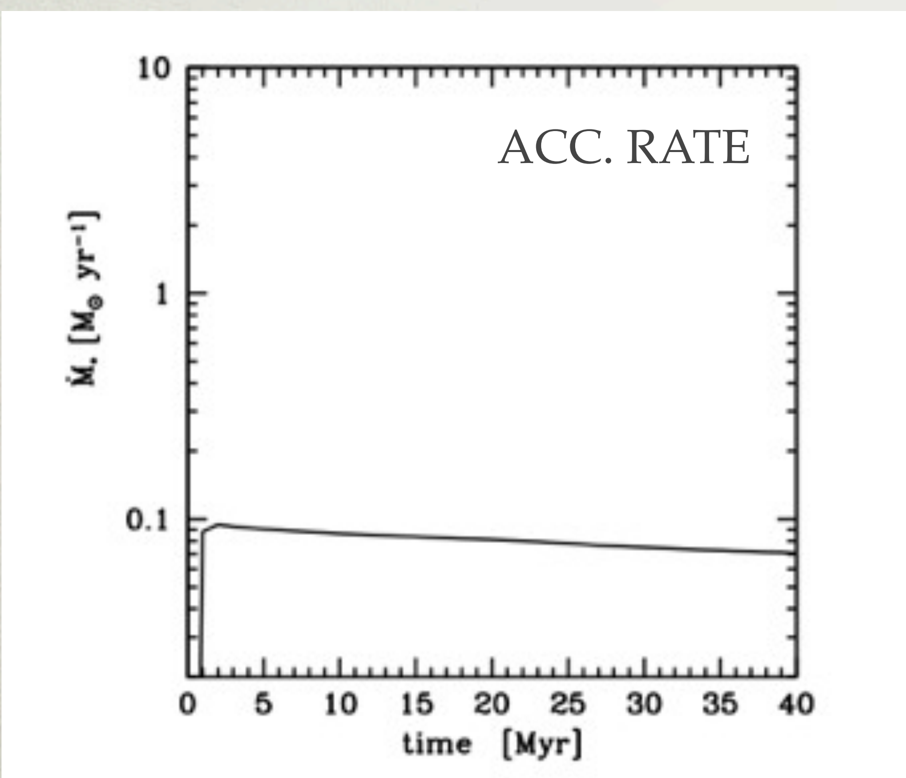
Chaotic Cold Accretion

(turbulence + cooling + heating)

PURE HOT MODE (BONDI)

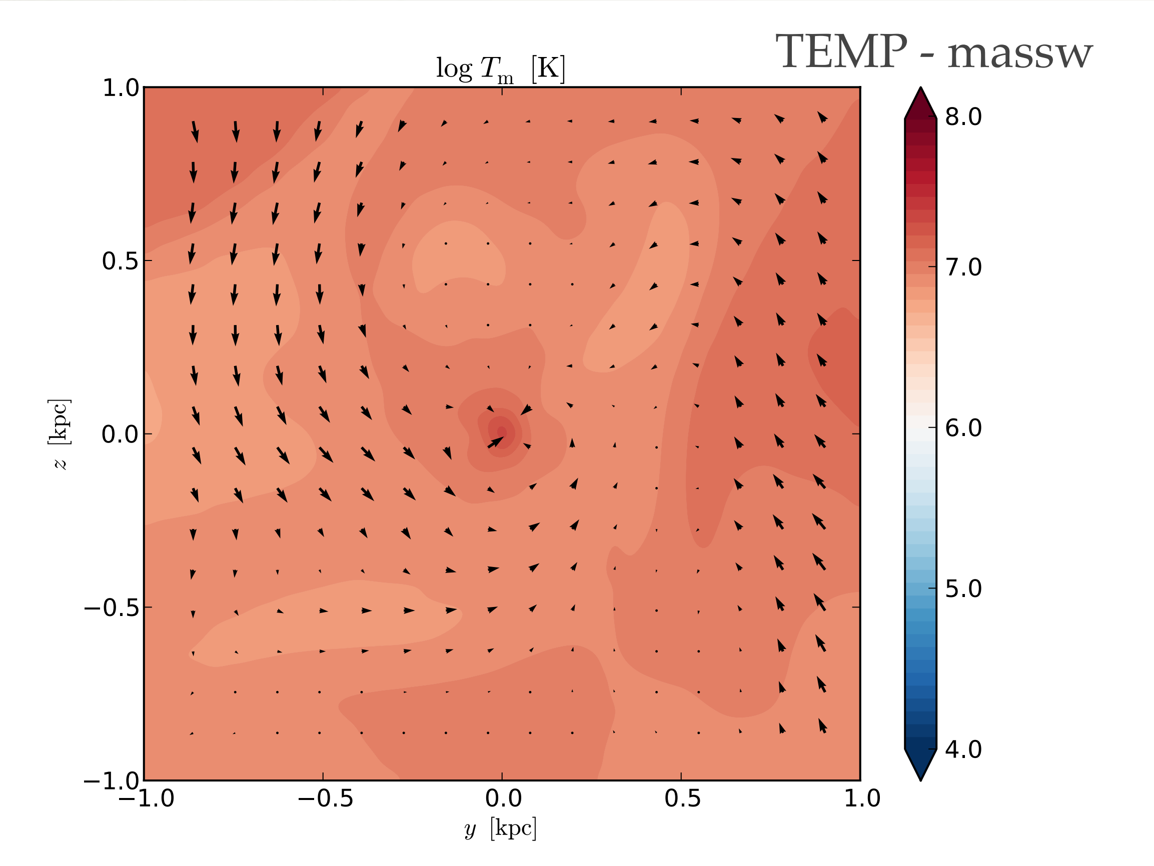


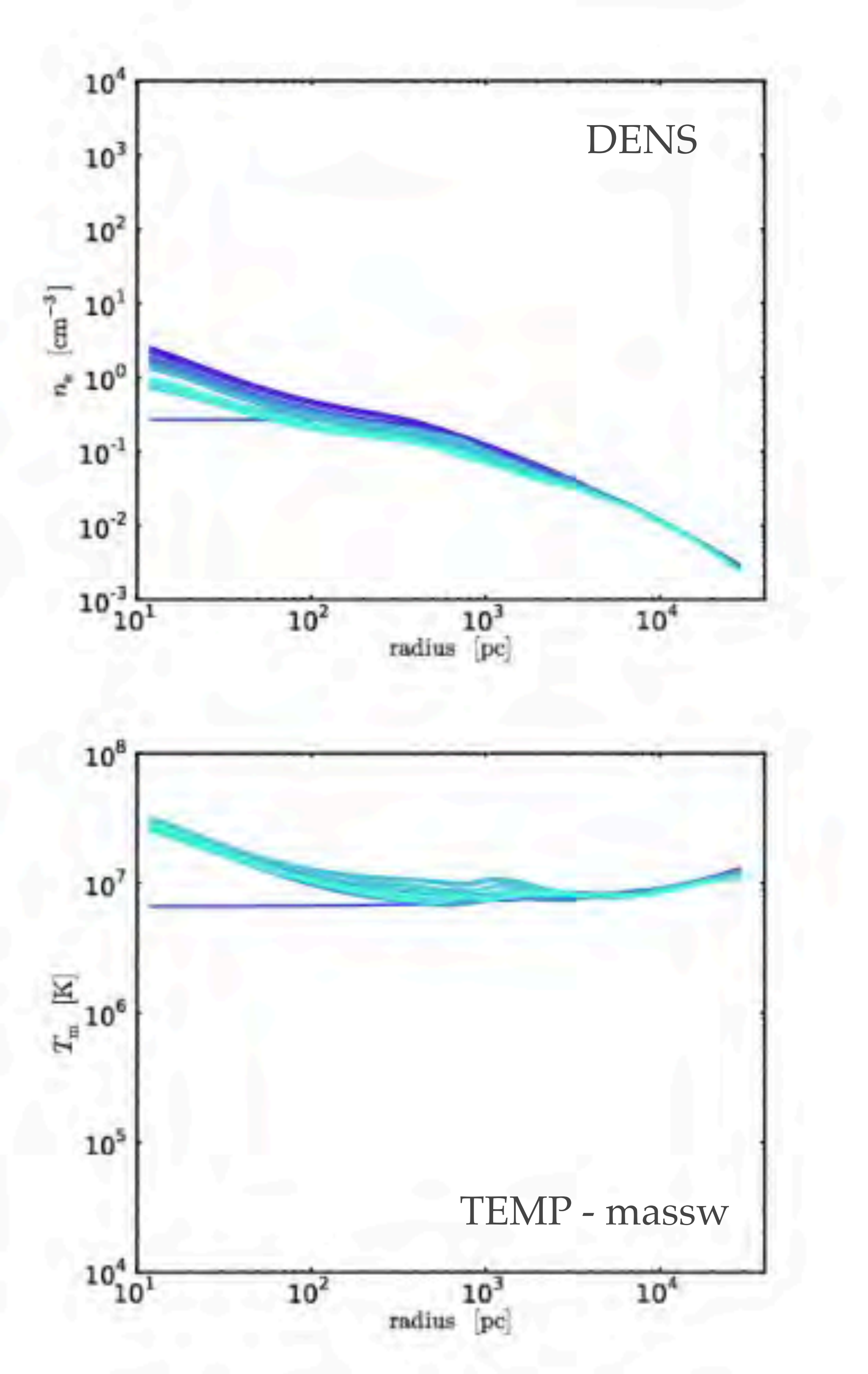


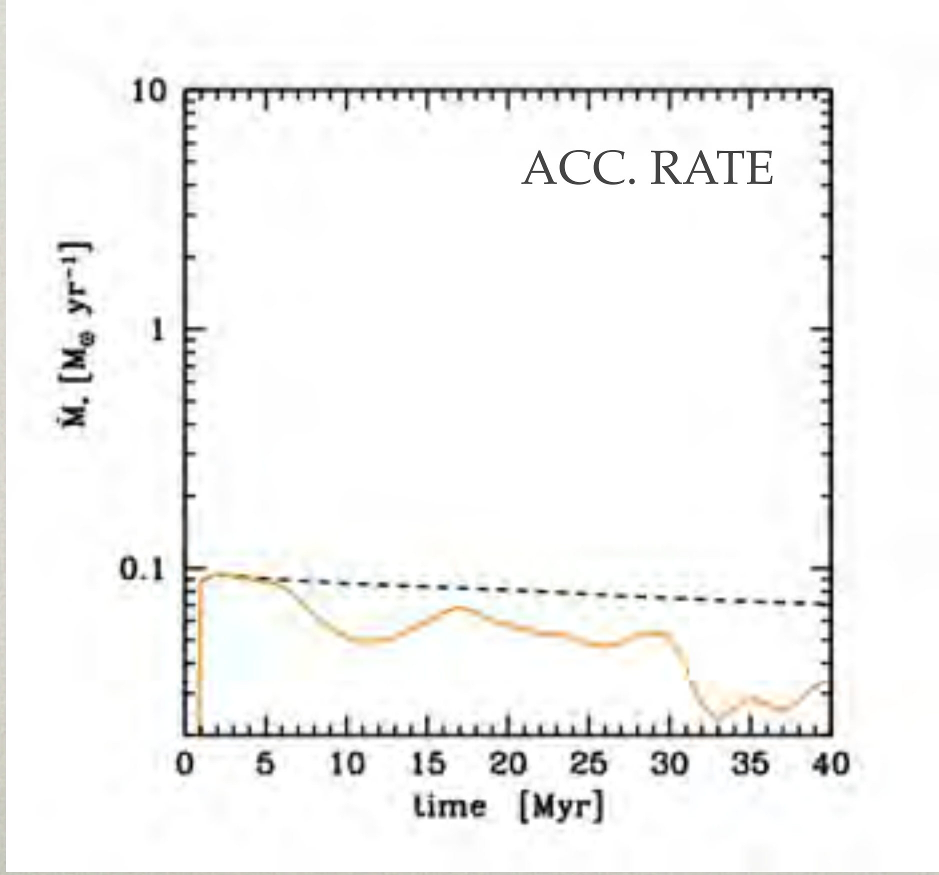


$$\dot{M}_{\rm Bondi} = 4\pi (GM_{\rm BH})^2 \rho_\infty / c_{s,\infty}^3$$

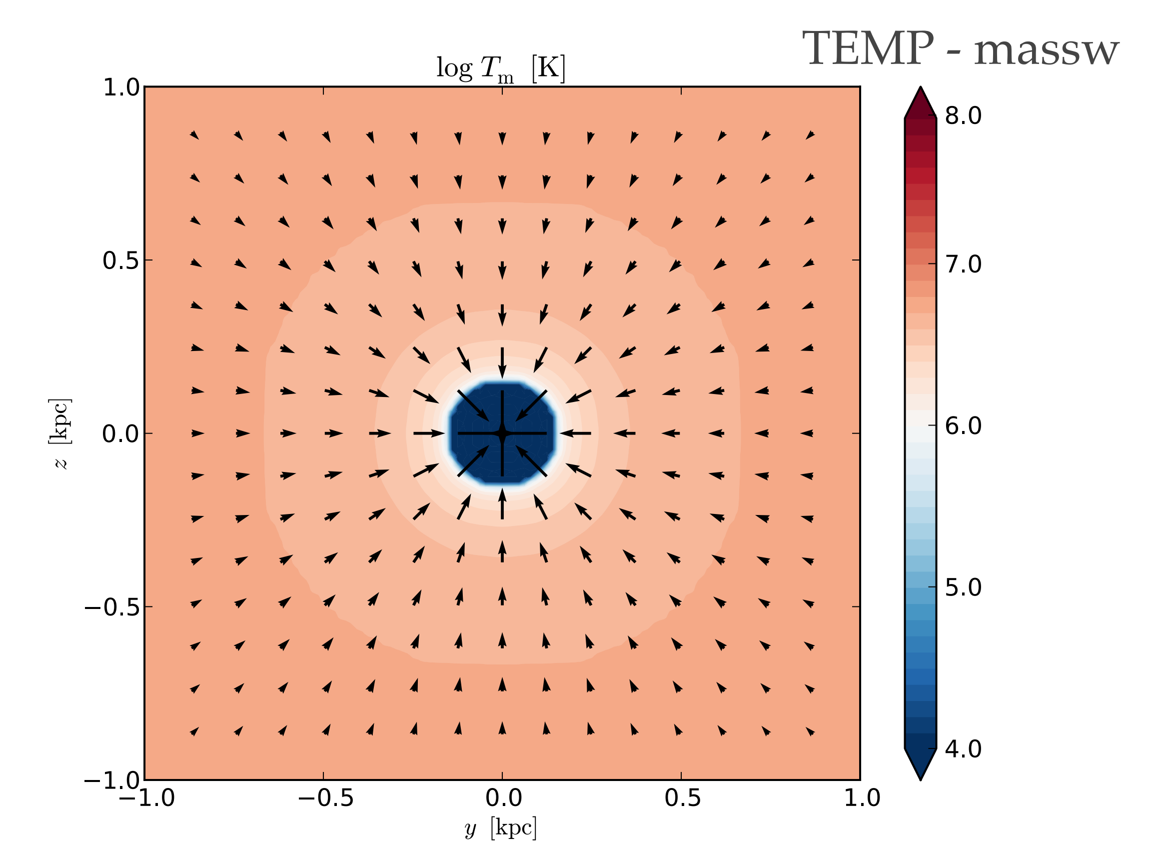
TURBULENT HOT MODE

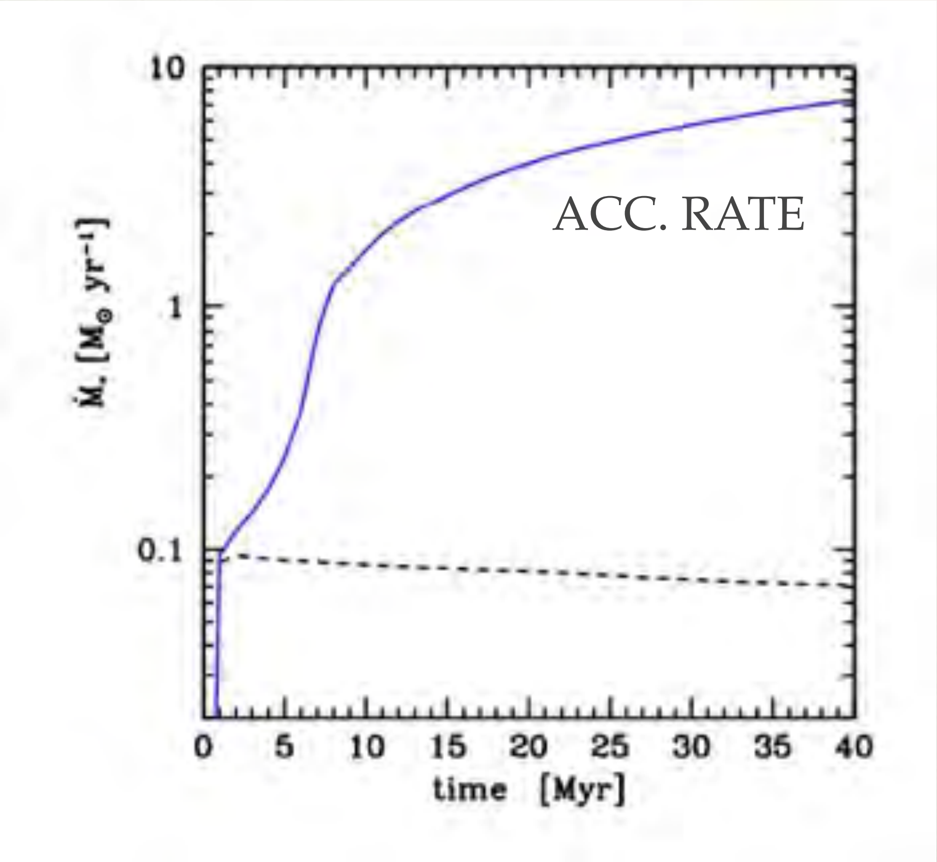


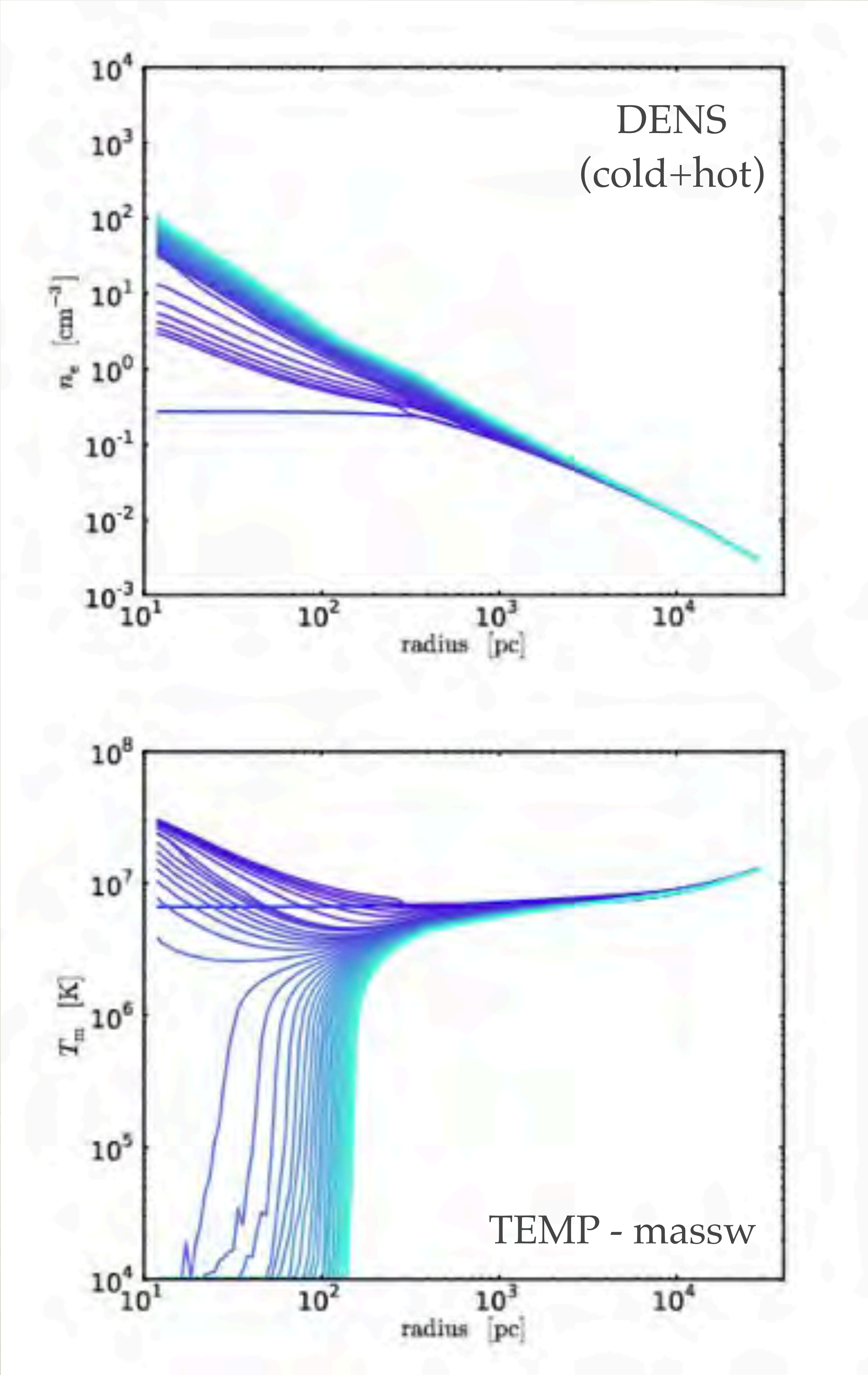




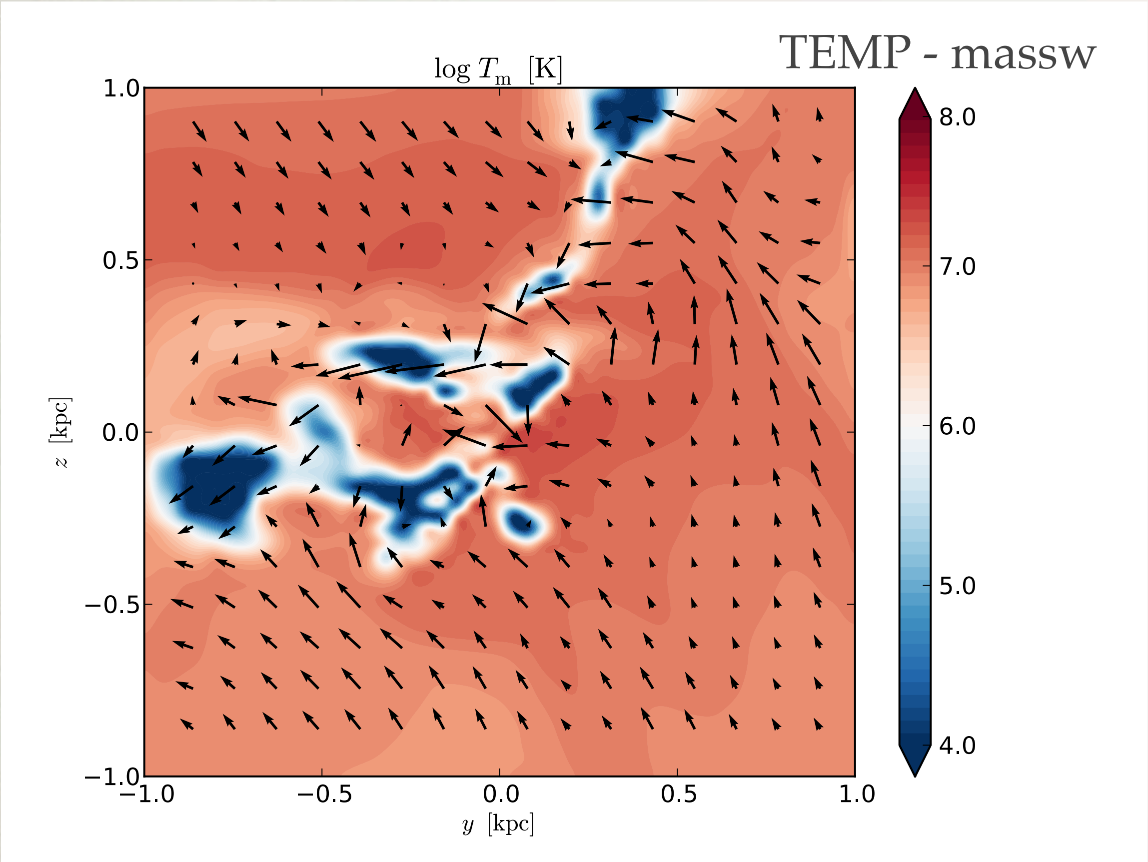
PURE COLD MODE

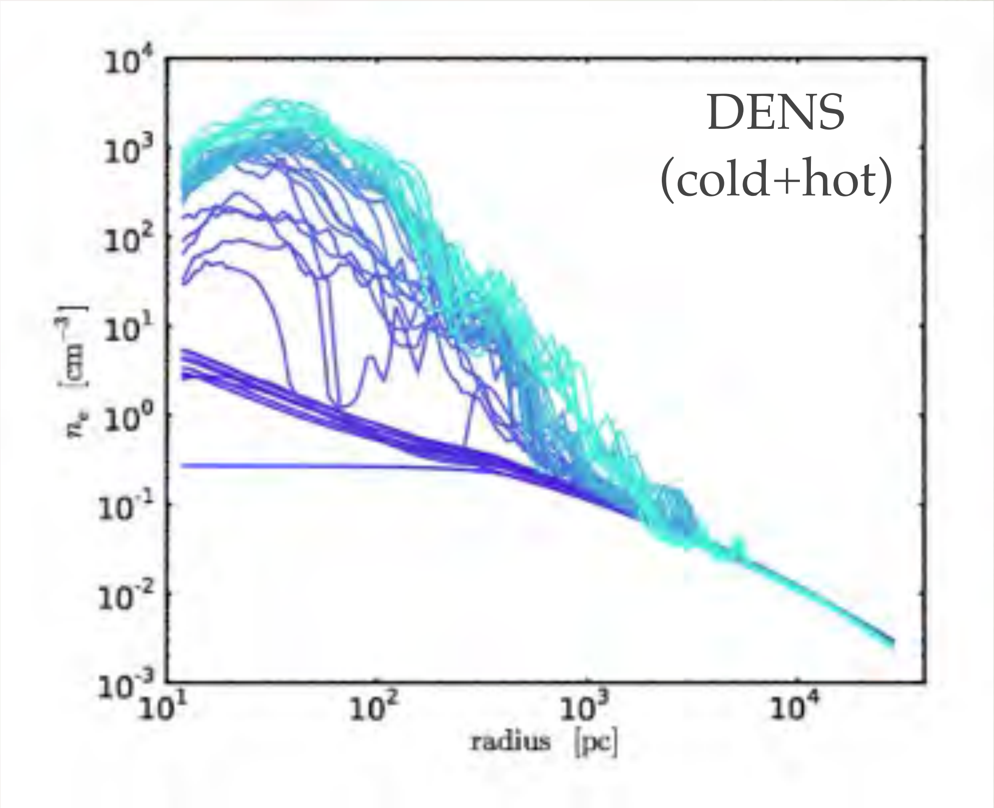


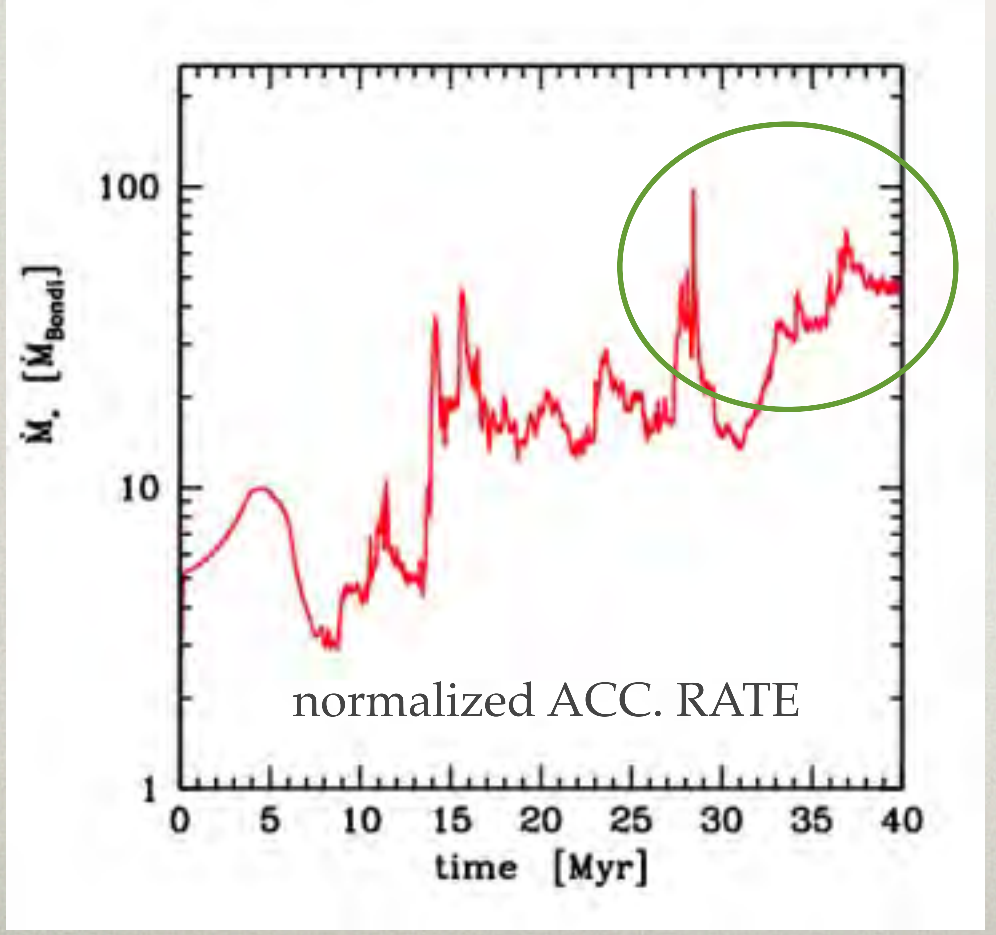


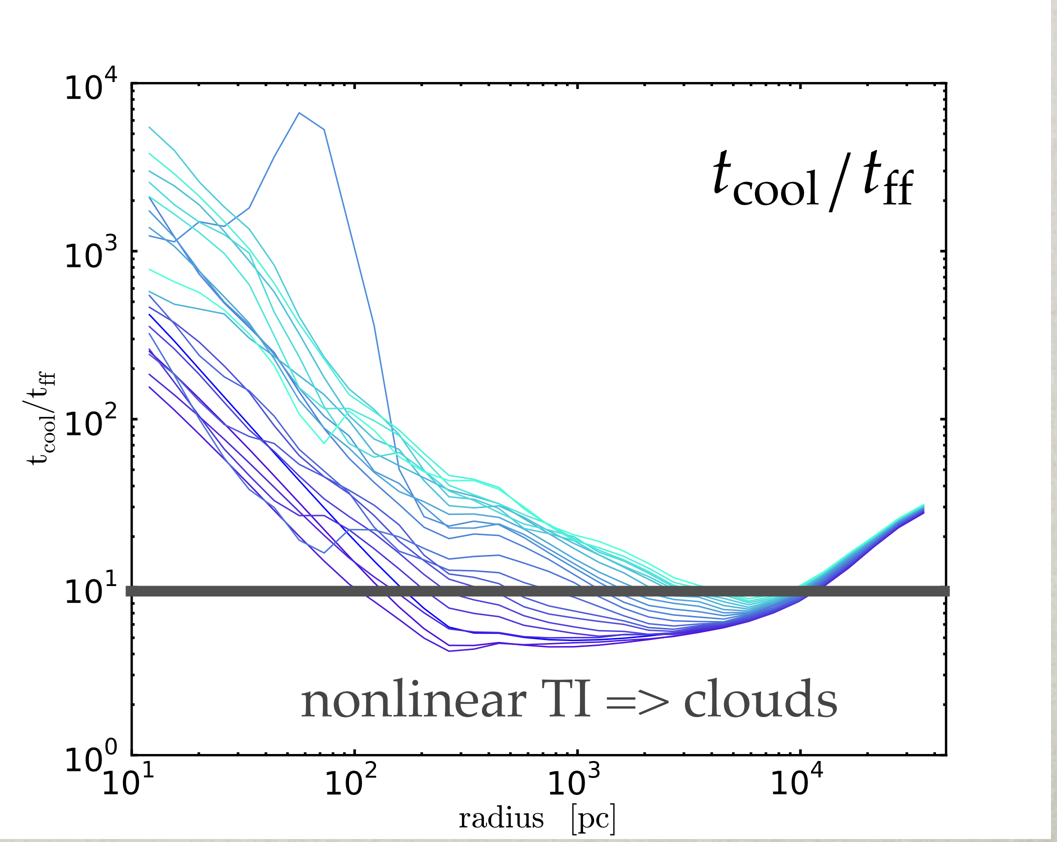


CHAOTIC COLD ACCRETION



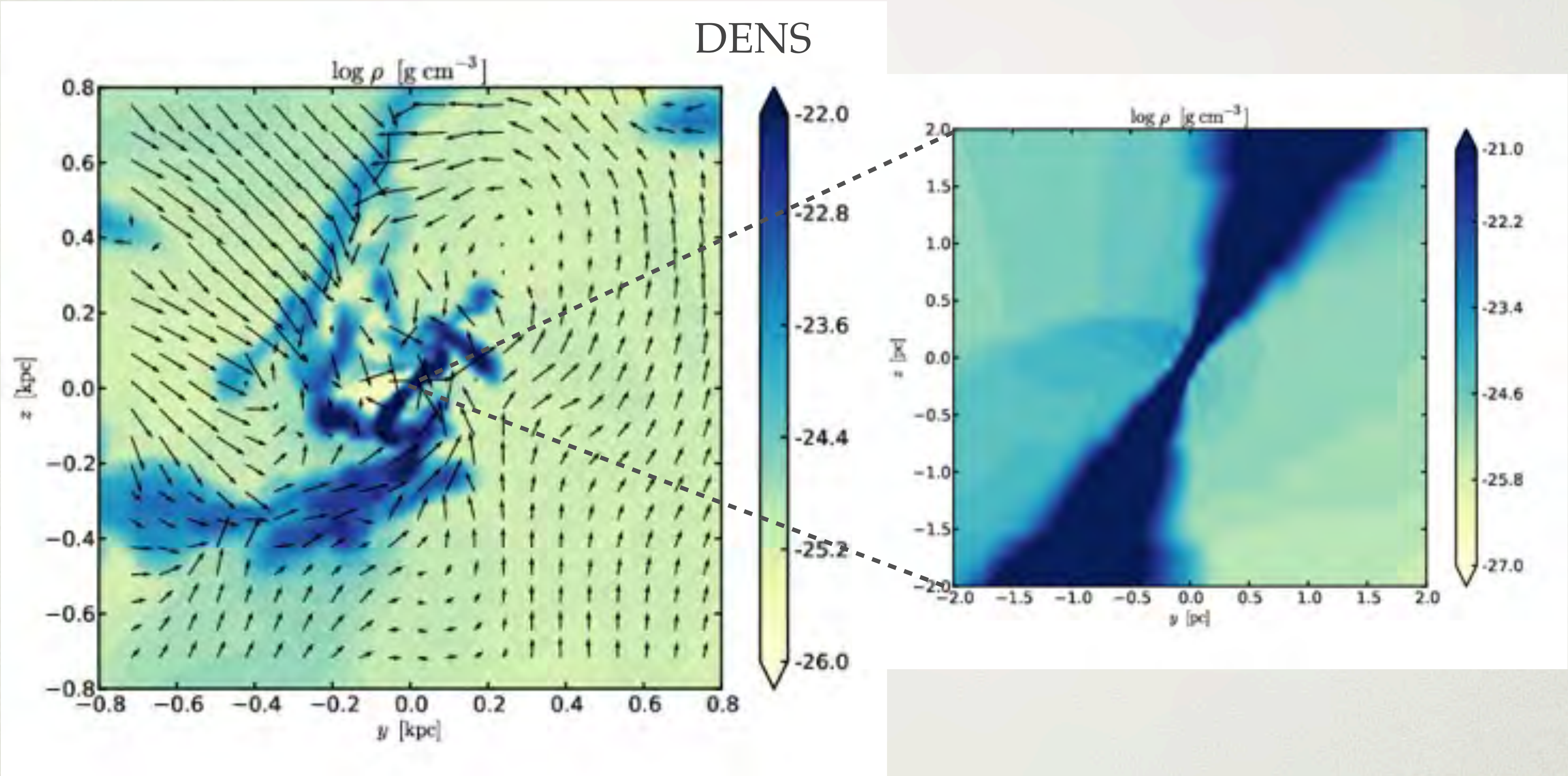






Thermal Instability

CHAOTIC COLD ACCRETION



- Accretion driven by **inelastic collisions**: cloud-cloud and cloud-torus
- Angular momentum cancellation
- Extremely clumpy & turbulent torus (key for the AGN unification theory)
- Cold clouds may form the BLR/NLR or HVC & induce large variations in L_{AGN}
- Deflection of jets/outflows & BH spin changes

5.

Chaotic Cold Accretion drives feedback:

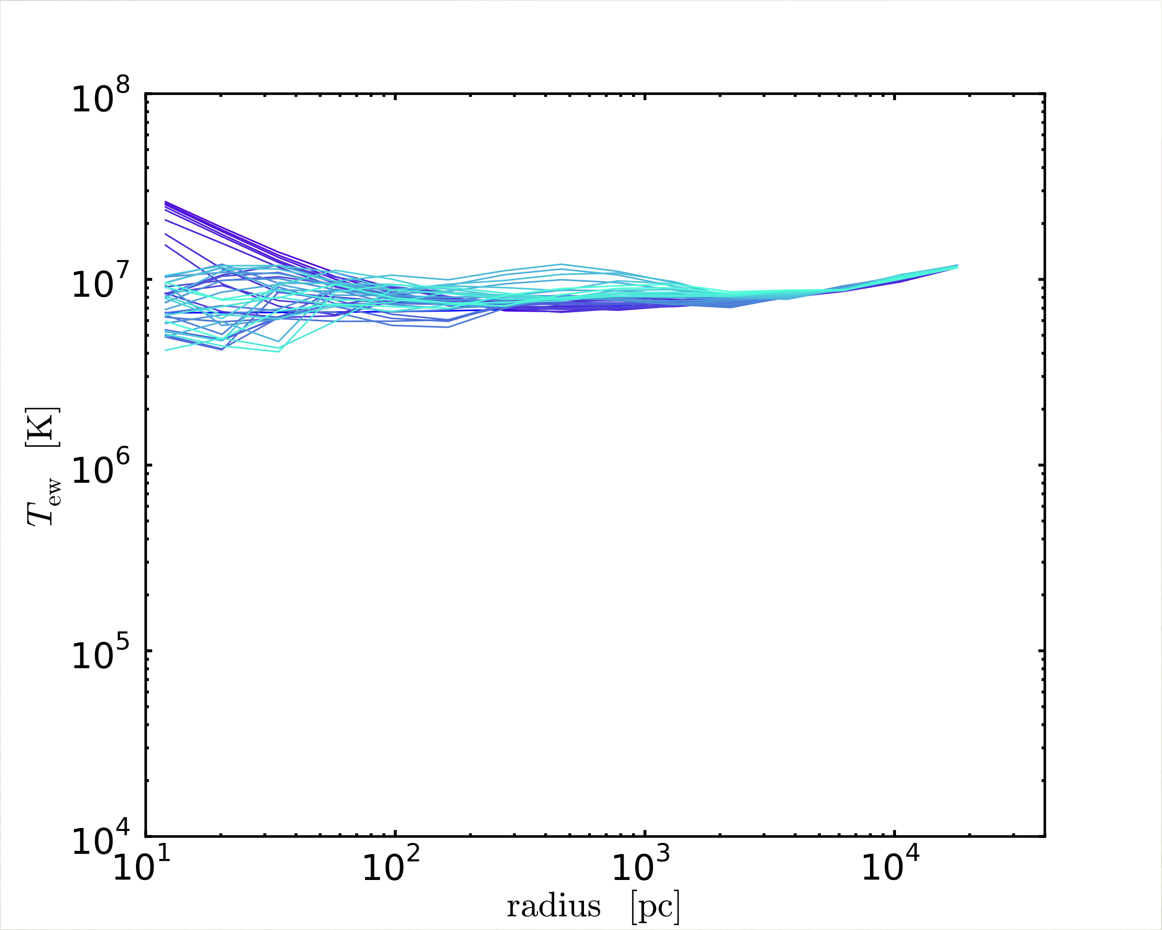
$$\dot{M}_{\rm BH} \sim 100\ \dot{M}_{\rm Bondi}$$

COLD vs HOT
ACCRETION

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

chaotic cold accretion

$$\dot{M}_{BH} \gg \dot{M}_{Bondi}$$

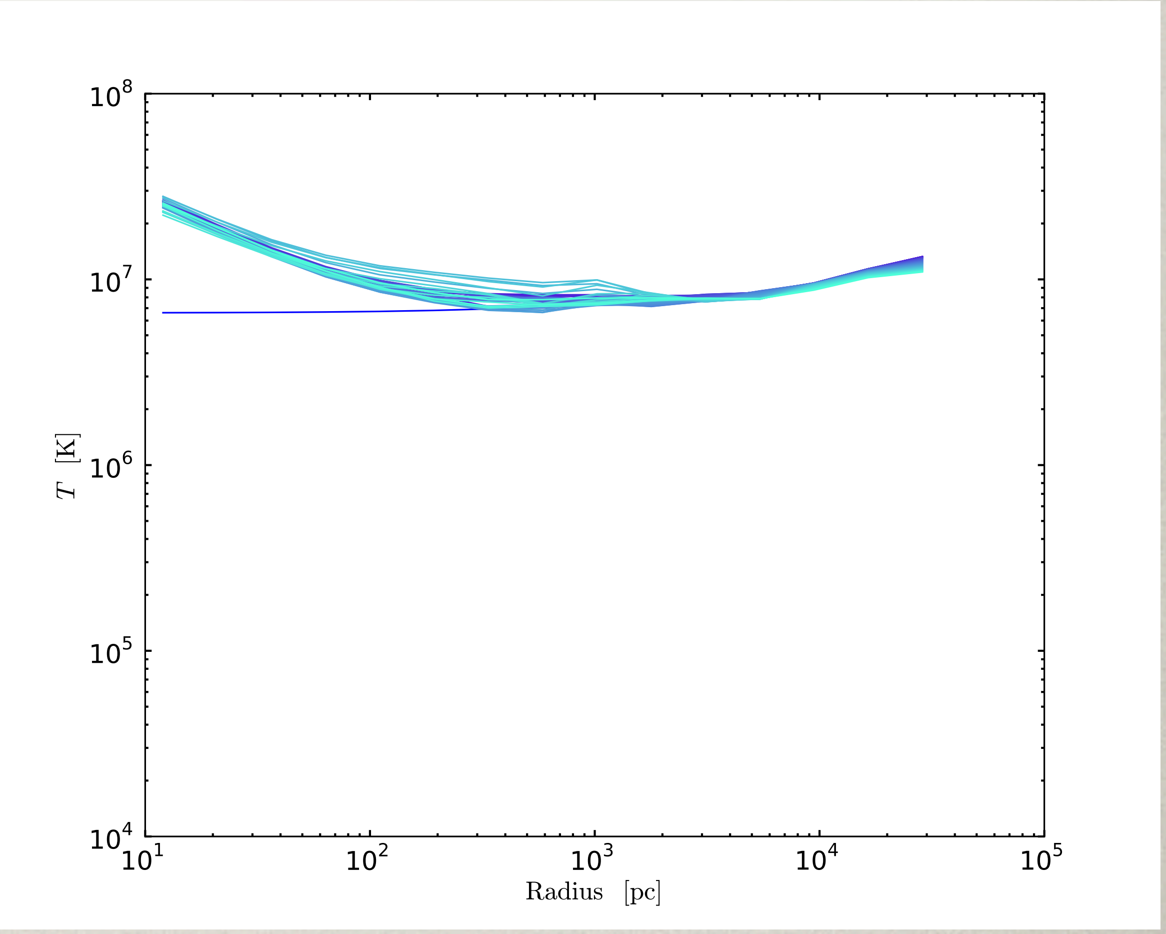


roughly flat T_X profile

- $t_{turb}/t_{cool} \lesssim$ **1 => turbulent heating**

stifled hot accretion

$$\dot{M}_{BH} \ll \dot{M}_{Bondi}$$



cuspy T_X profile

(CHAOTIC) COLD FEEDBACK

$$\dot{M}_{\rm BH} \sim \dot{M}_{\rm cool}$$

- Fast communication time between the gas and the black hole

- Tight symbiosis between the BH and the whole galaxy => Magorrian relation

$$M_{\rm BH} \propto M_{\rm gas} \longleftrightarrow M_{\rm BH} \propto M_*$$

- Substantial accretion rates + recurrent cycle => efficient feedback

- **Simple yet powerful subgrid model for cosmological simulations**, instead of boosting the Bondi rate by the ad-hoc factor:

$$\alpha_{\rm boost} \sim 50 - 100$$

SELF-REGULATED AGN FEEDBACK

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

↓

$t_{\rm cool}/t_{\rm ff} \lesssim 10$ ← turbulence > 100 km/s

↓

TI: cold clouds
→ clumpy torus & filaments (10 kpc)
→ tight symbiosis BH - *whole* galaxy: (Magorrian relation)

↓

chaotic collisions: $\dot{M}_{\rm BH} \sim 100\ \dot{M}_{\rm Bondi} \sim \dot{M}_{\rm cool}$

↓

mechanical feedback
→ gently quench the cooling flow
→ bubbles, shocks, metal uplift, additional turbulence

↓

$t_{\rm cool}/t_{\rm ff} > 10$; $t_{\rm cool}/t_{\rm turb} > 1$

↓

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

↓

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

chaotic COLD mode (flat T_X profile)

stifled HOT mode (cuspy T_X profile)