UNIFYING THE MICRO AND MACRO PROPERTIES OF AGN FEEDBACK AND FEEDING

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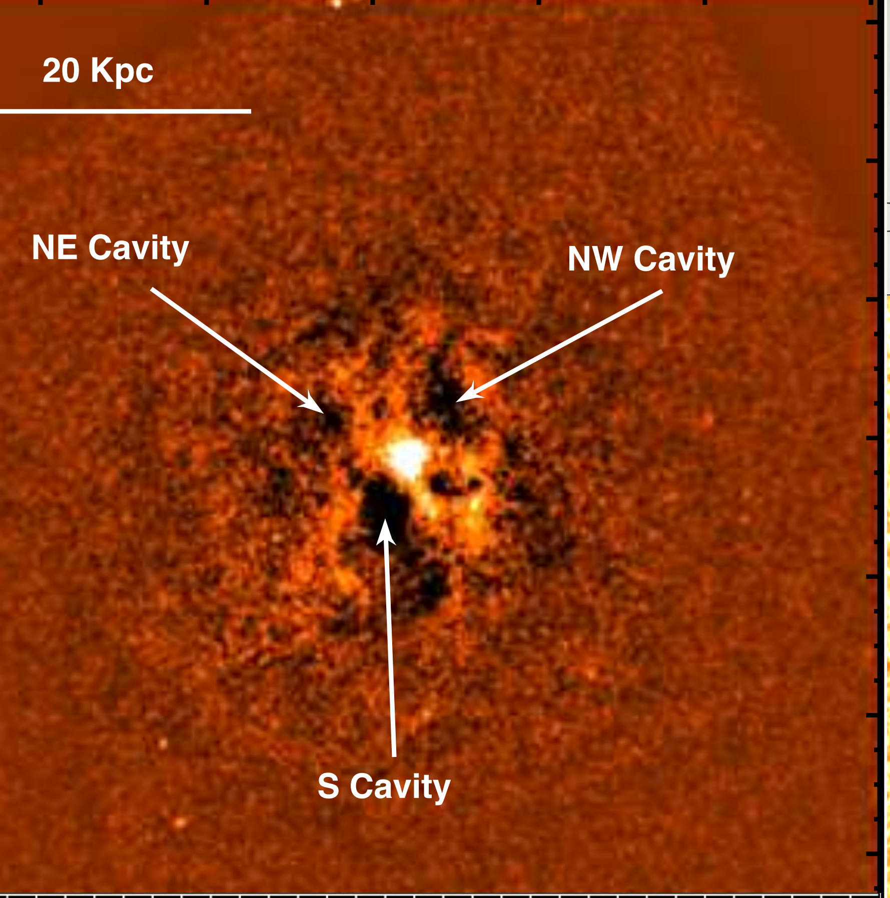
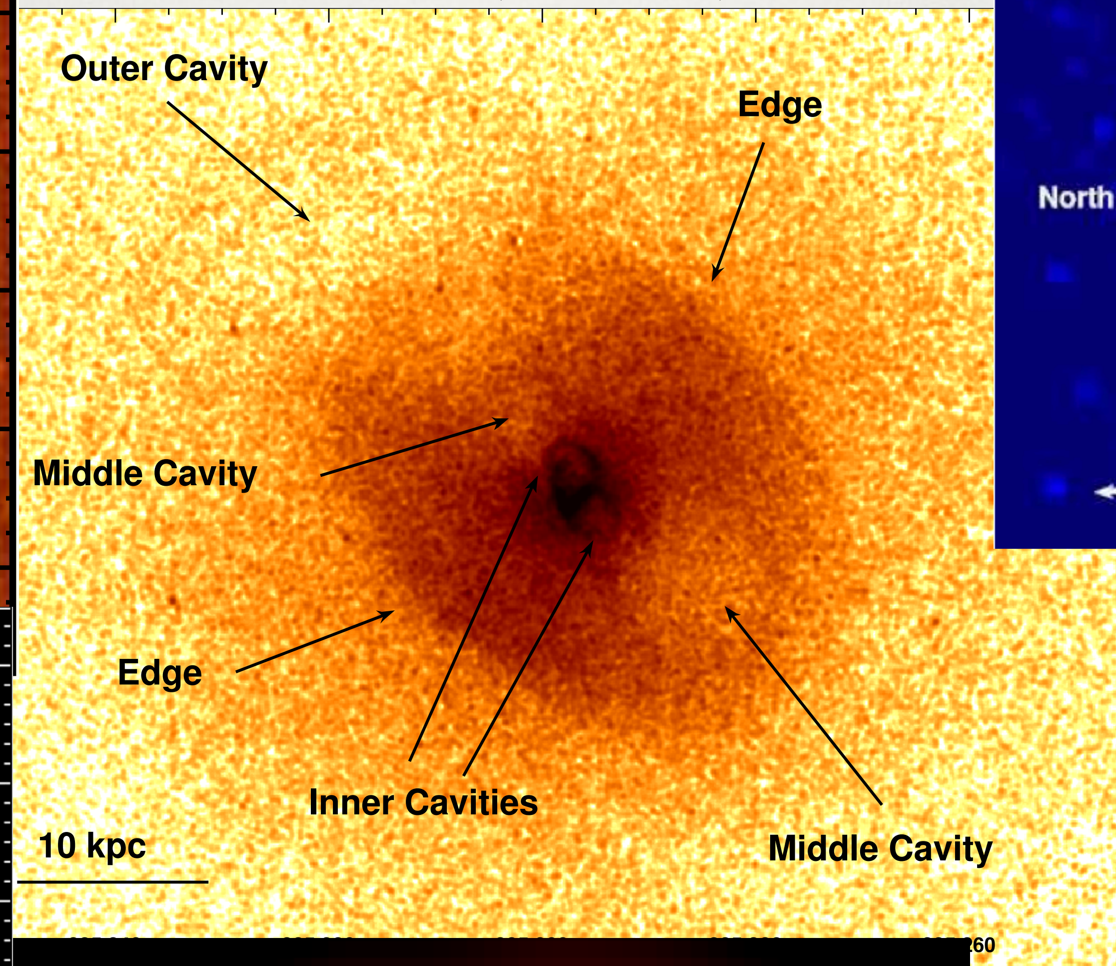
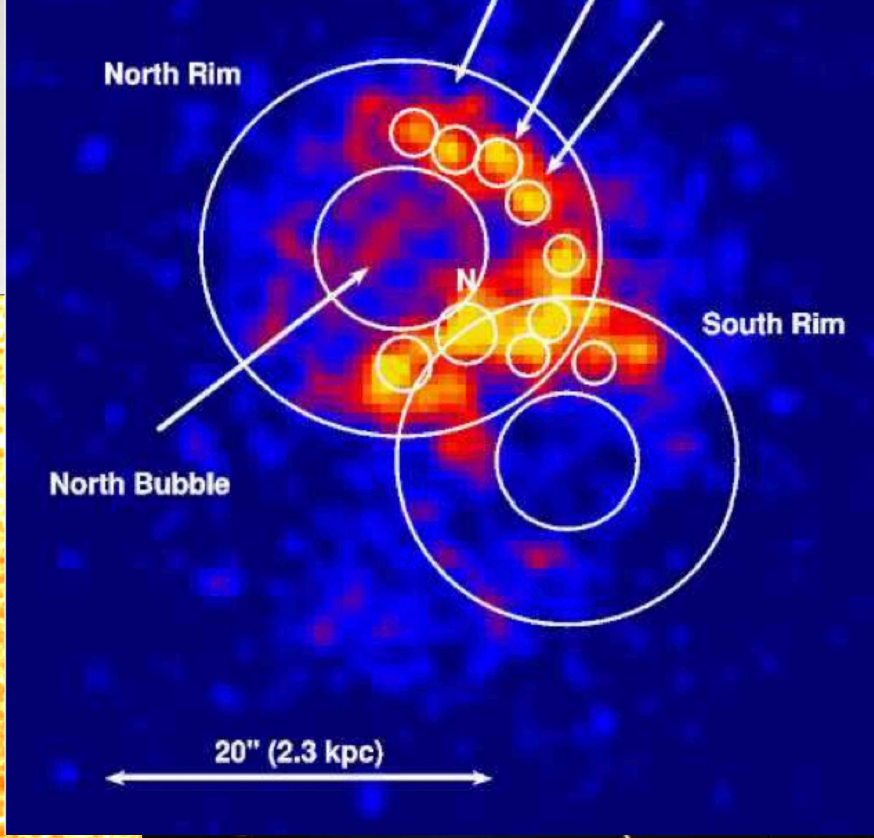
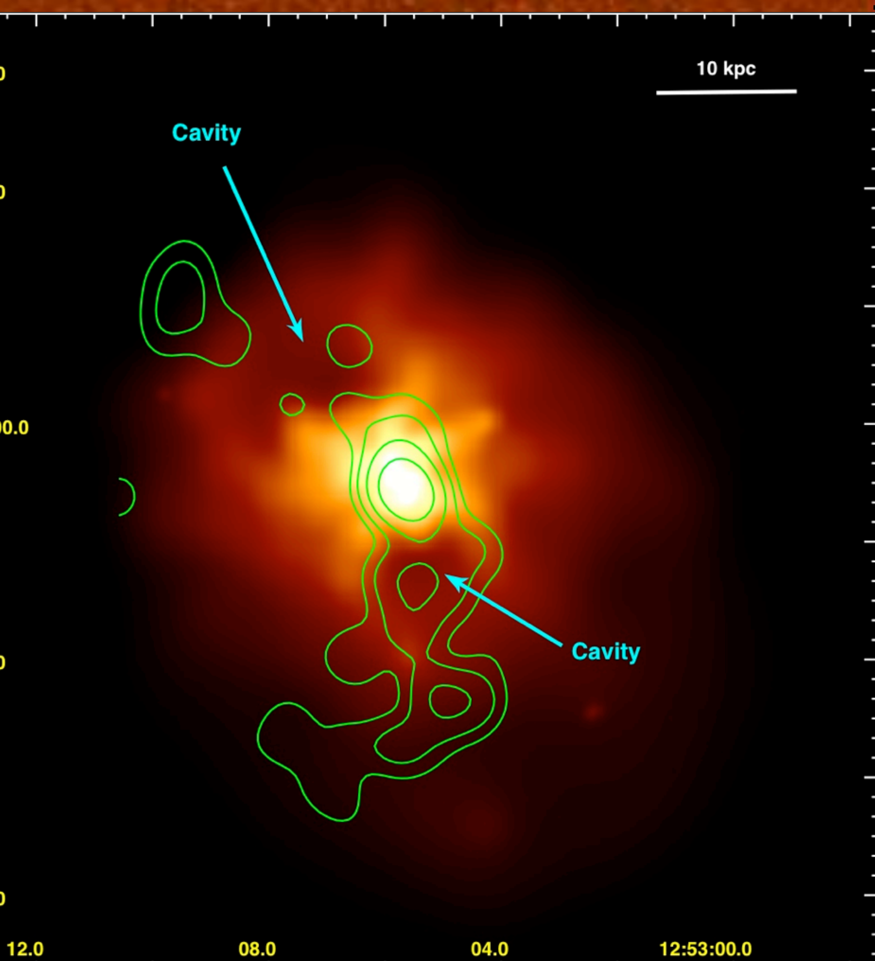
HOT HALOS

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

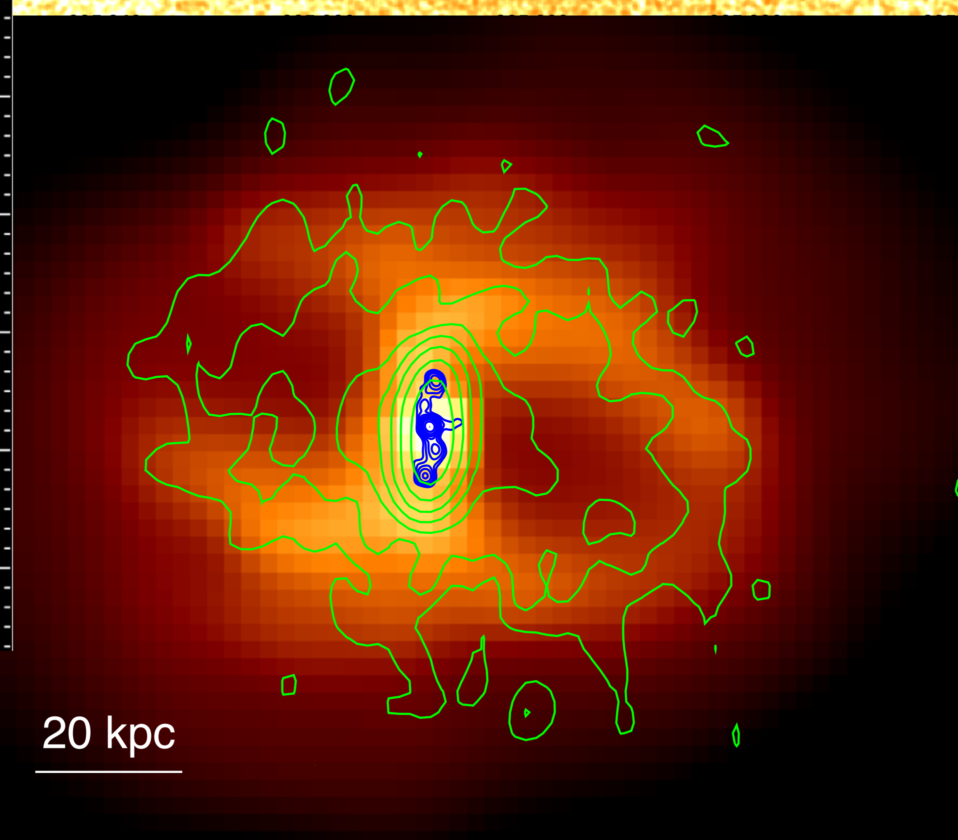




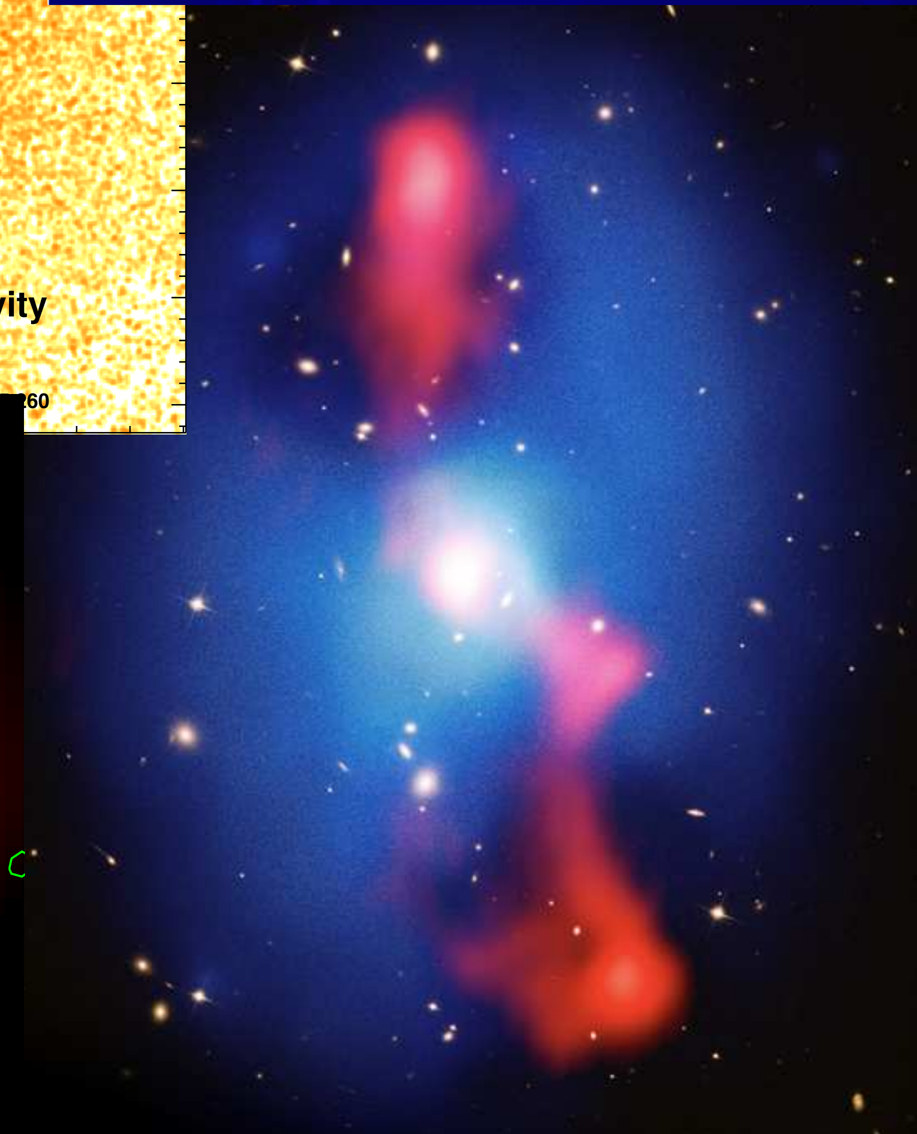




HCG 62 (Gitti+10)

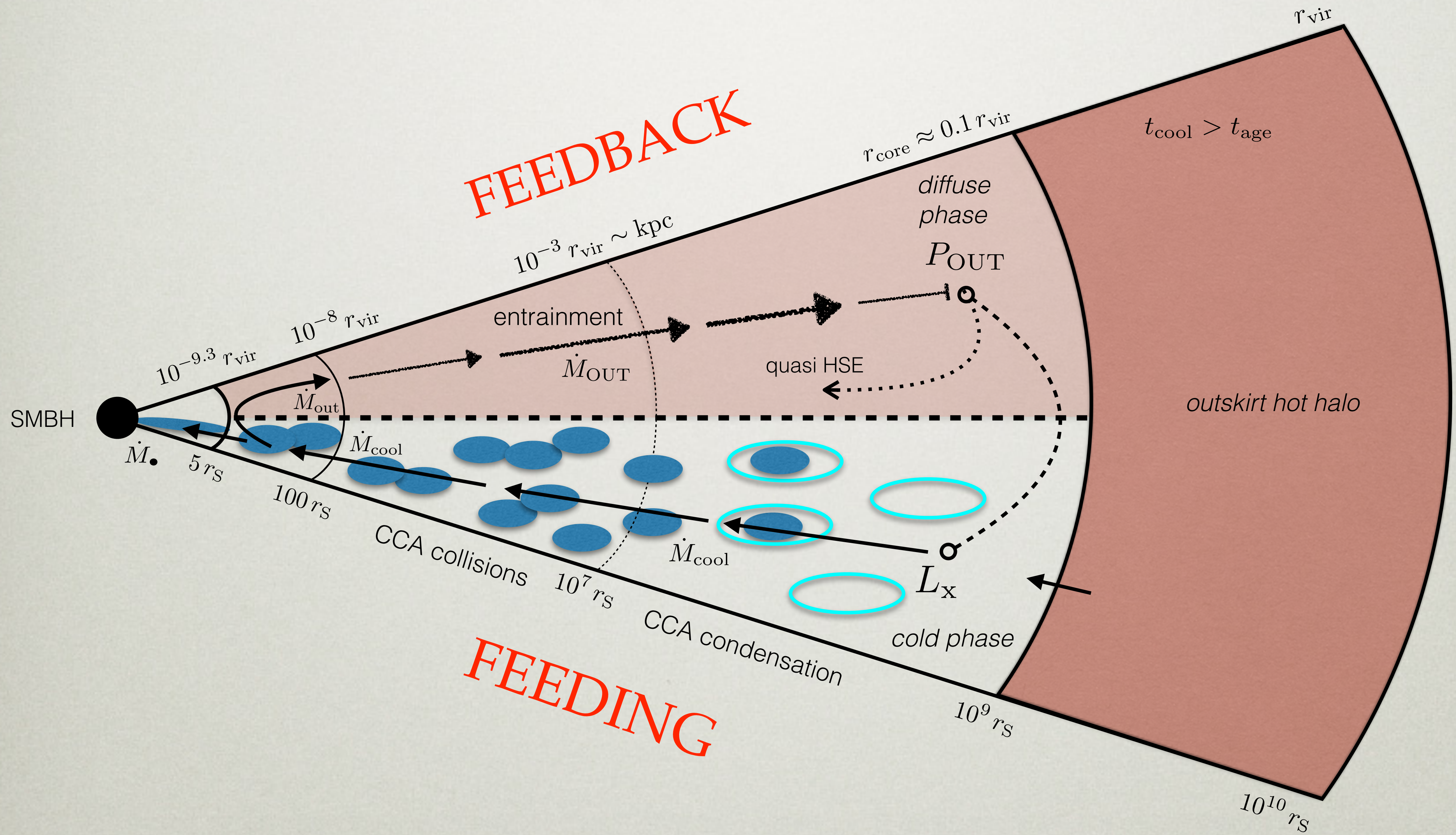


RBS 797
(Gitti+11)



MS0735.6 cluster (McNamara+05)

AGN FEEDING AND FEEDBACK UNIFICATION

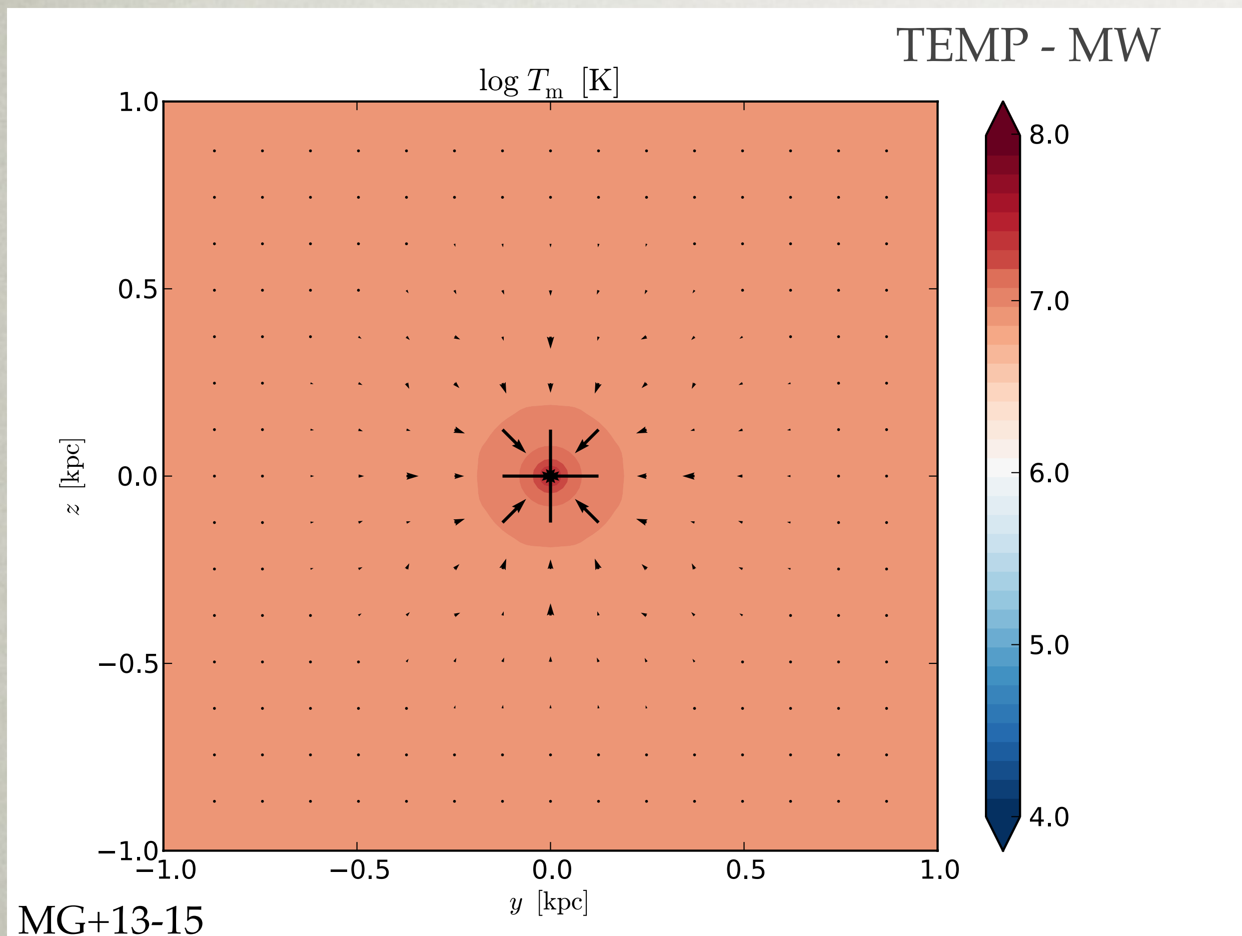


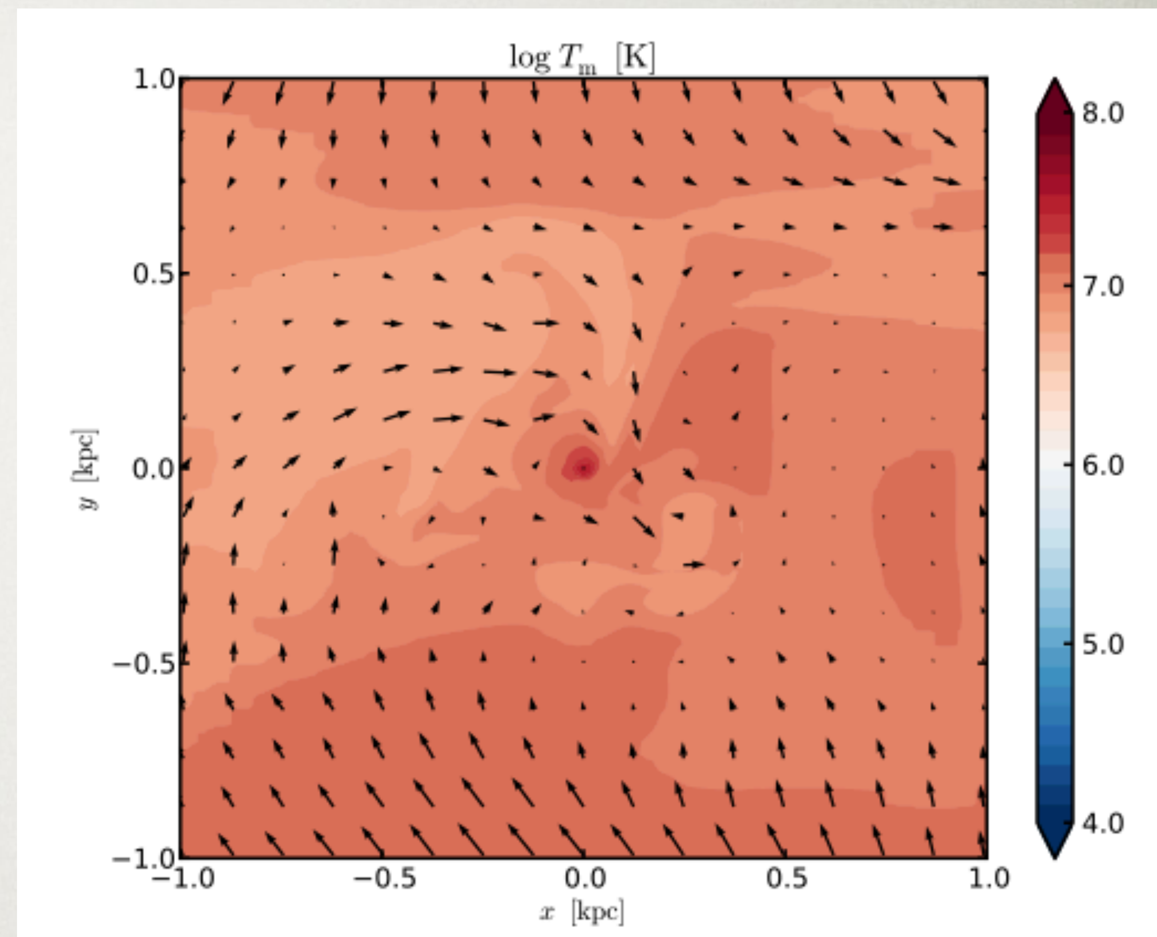
MG+2017

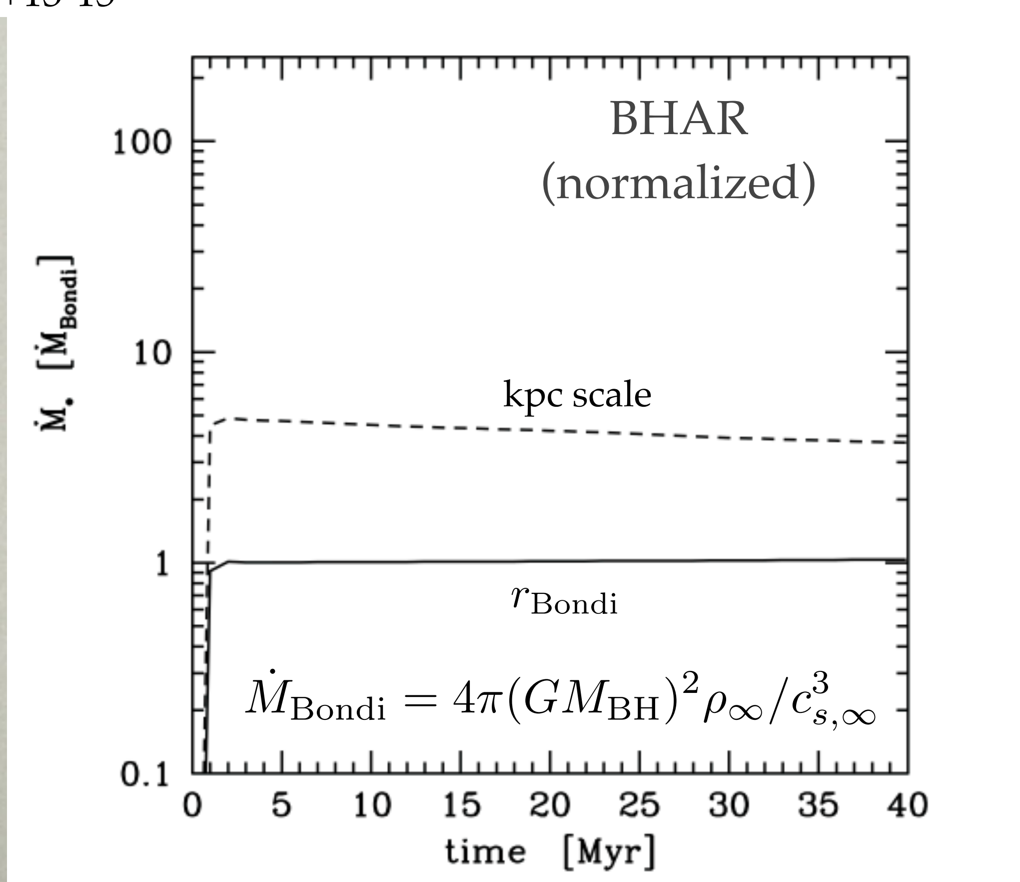
AGN FEEDING: HOT MODE

quiescent

turbulent or rotating



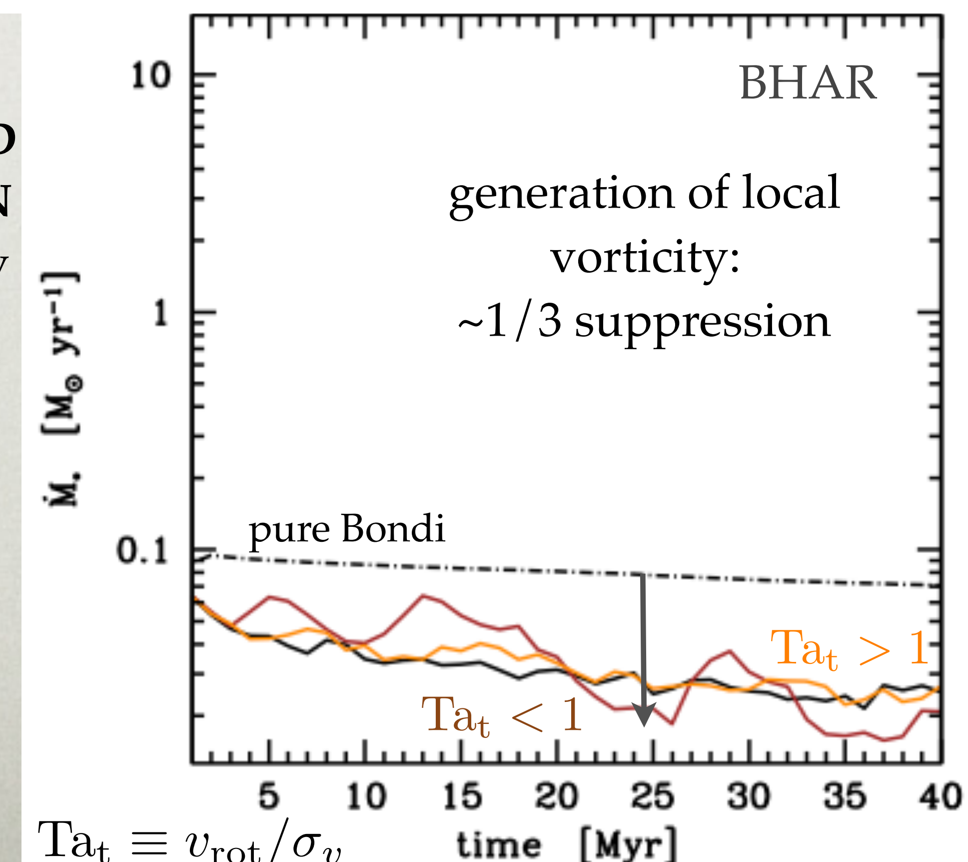




HIGH-RES HD SIMULATION

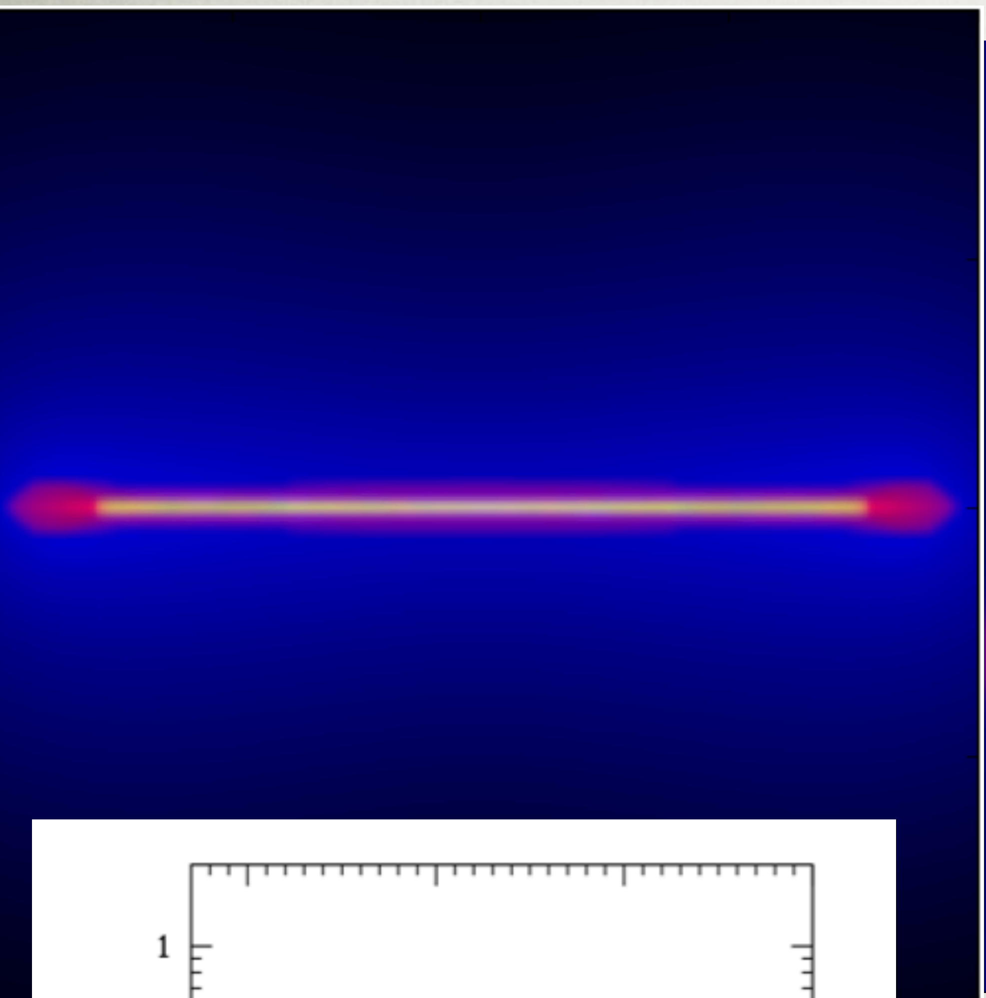
massive galaxy

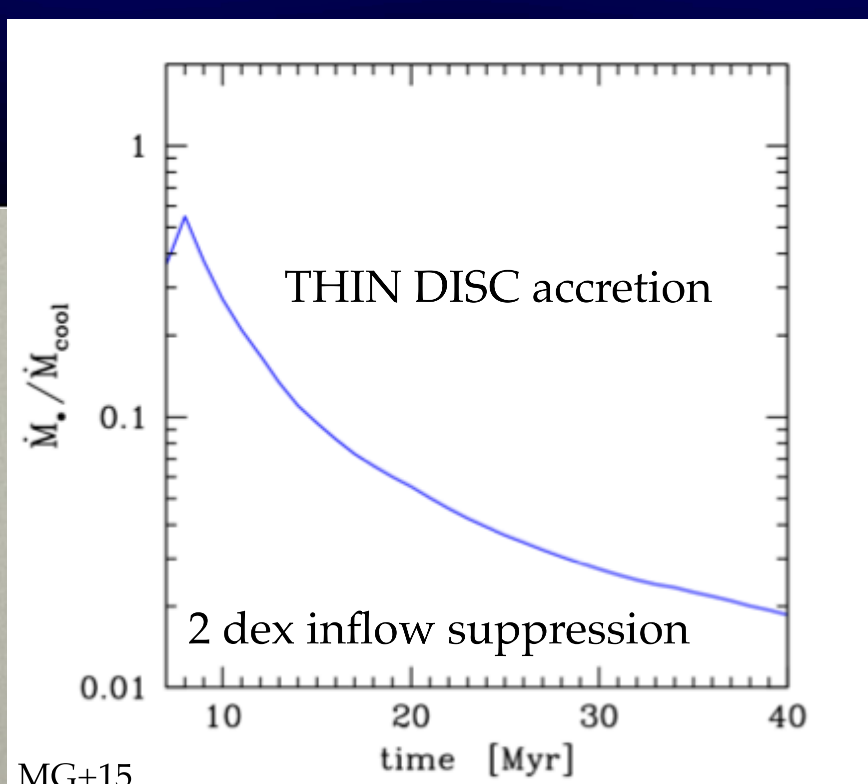
typically too low and smooth



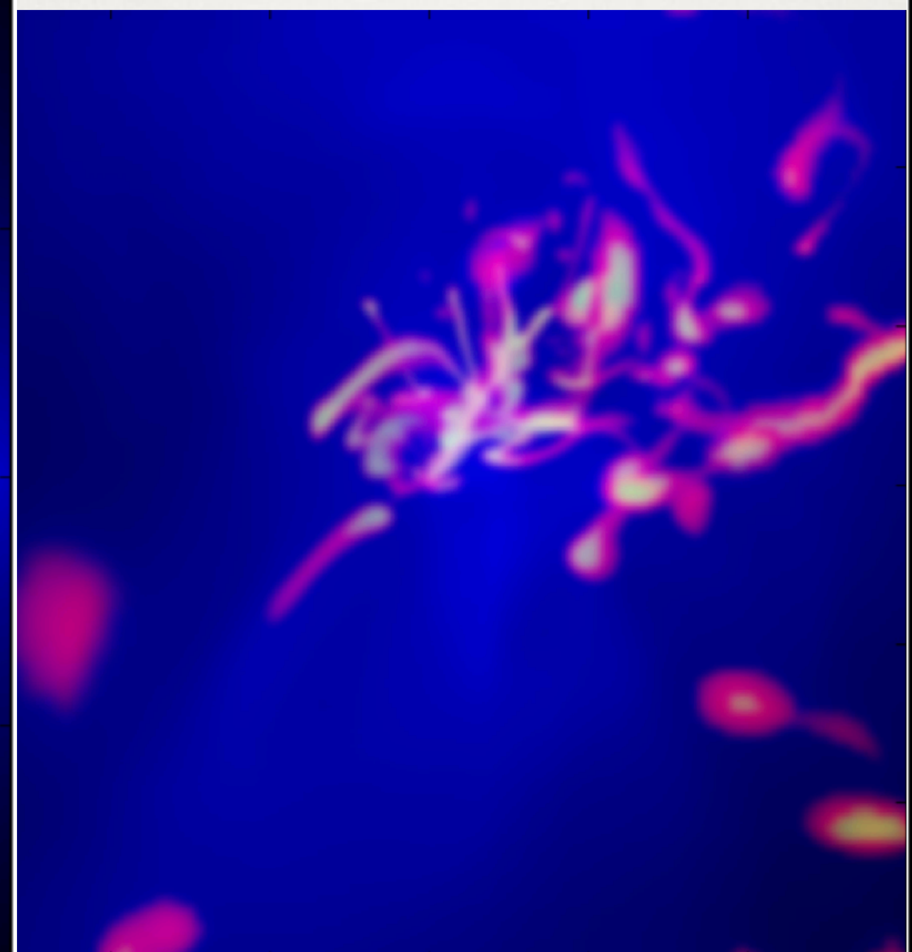
AGN FEEDING WITH COOLING: 3 DYNAMICAL STAGES

rotating



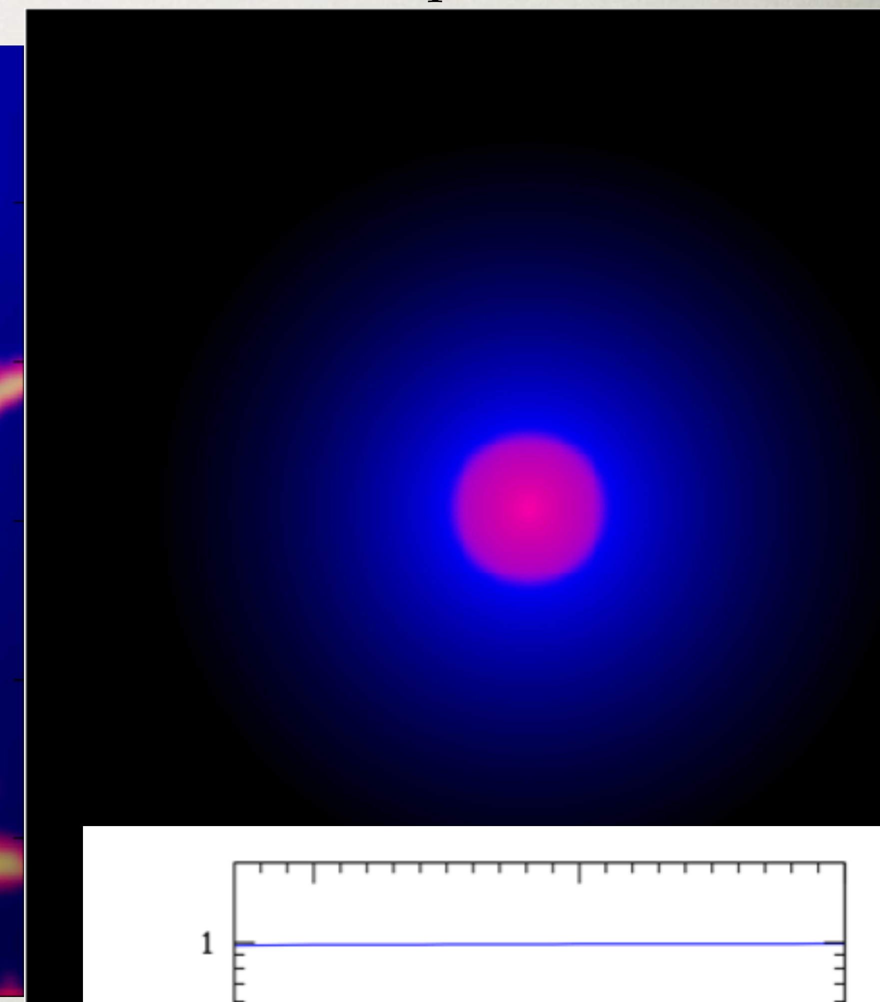


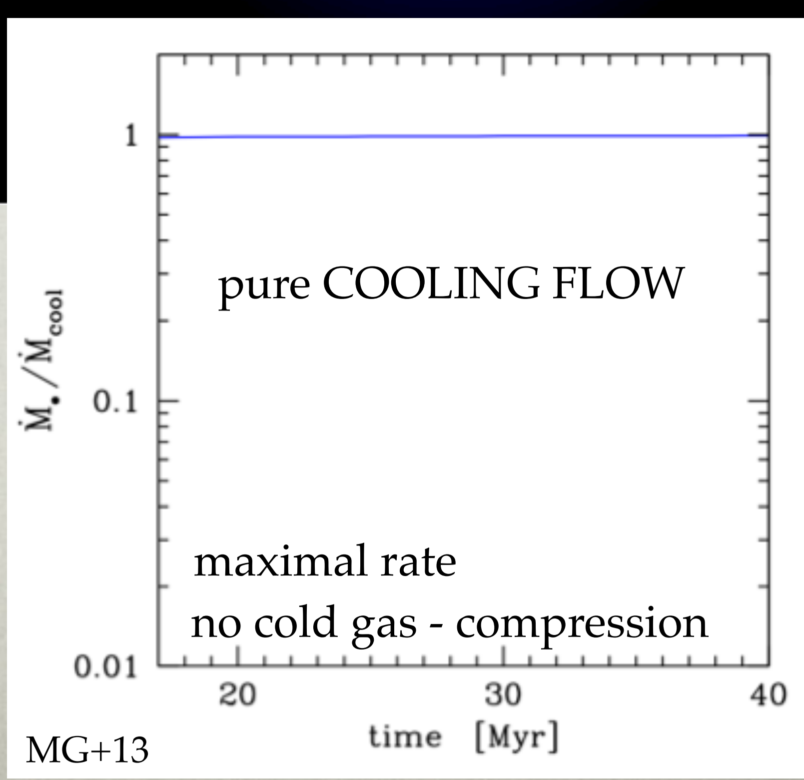
turbulent



RGB surface density: plasma (blue), warm gas (red), cold gas (green)

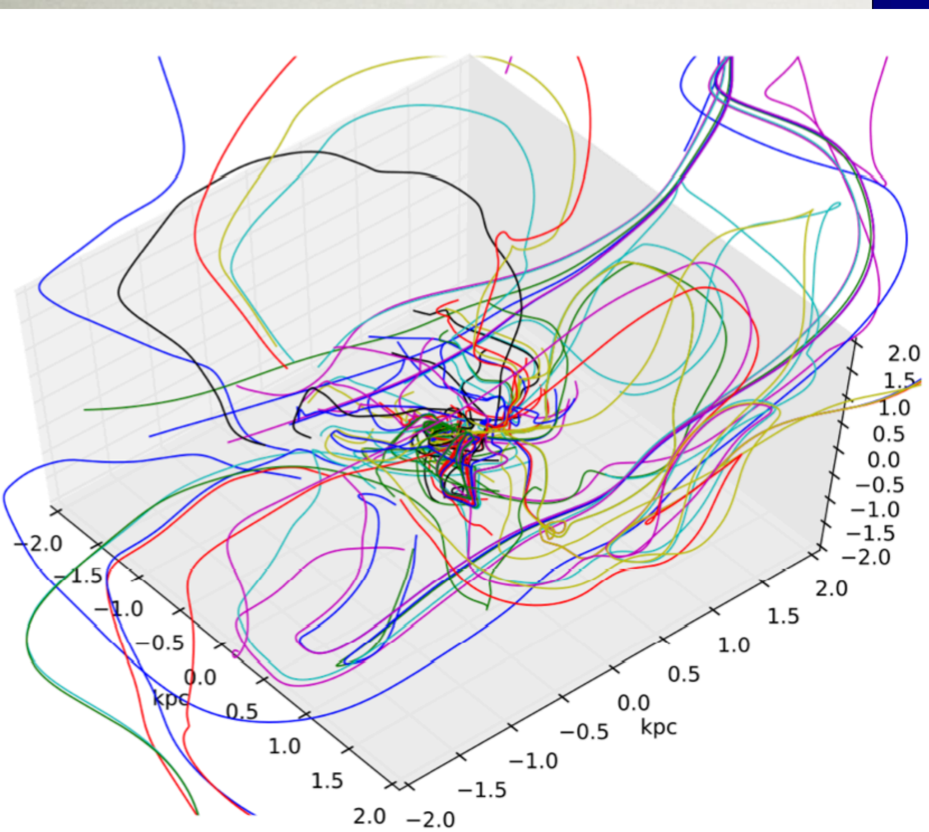
quiescent



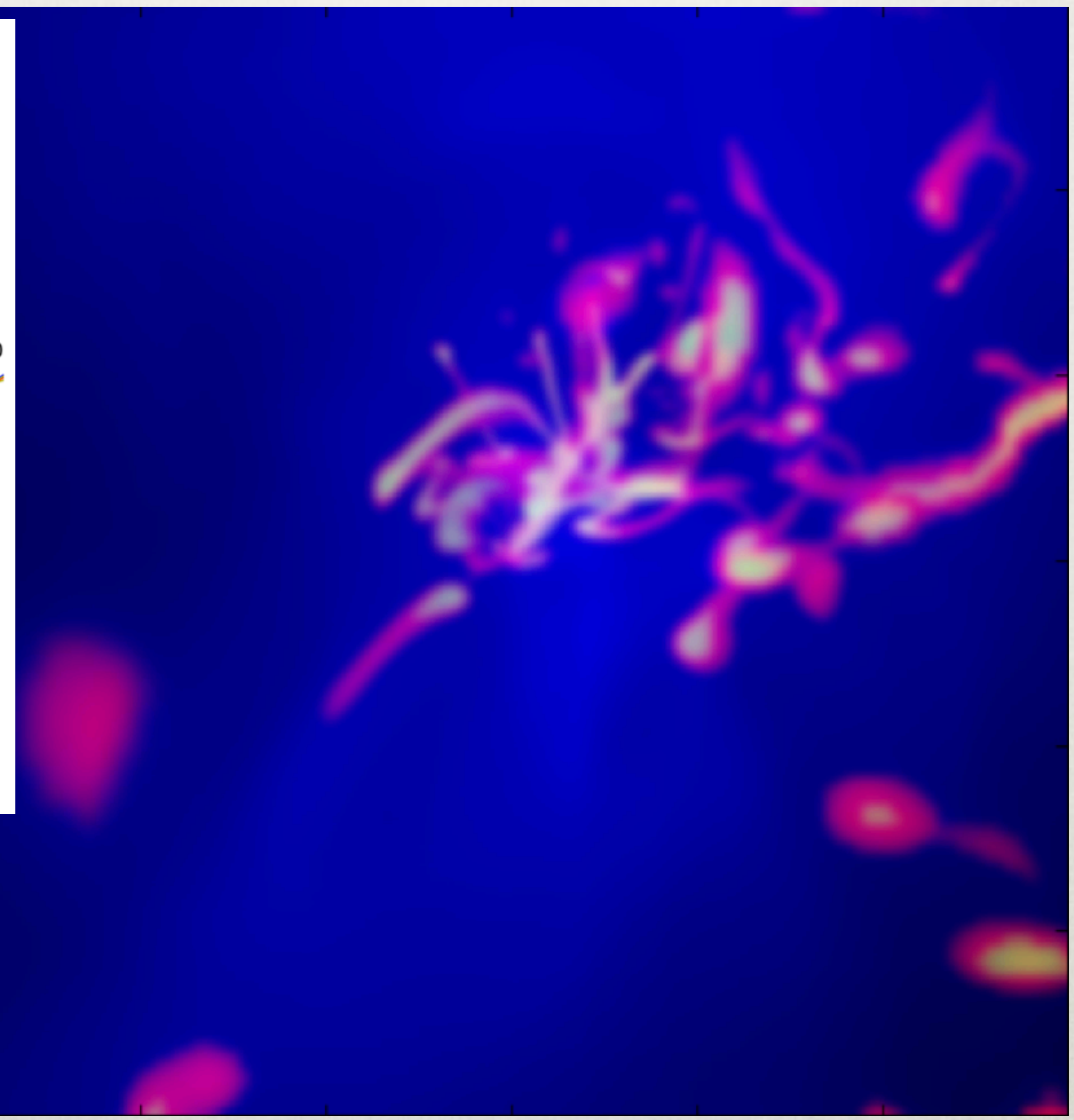


RAINING ON BLACK HOLES

Chaotic Cold Accretion [CCA]



chaotic streamlines => recurrent multiphase gas interactions



TURBULENCE > ROTATION

COOLING ~ AGN HEATING

turbulence ~160 km/s, as found (a posteriori) by *Hitomi*

MG+17

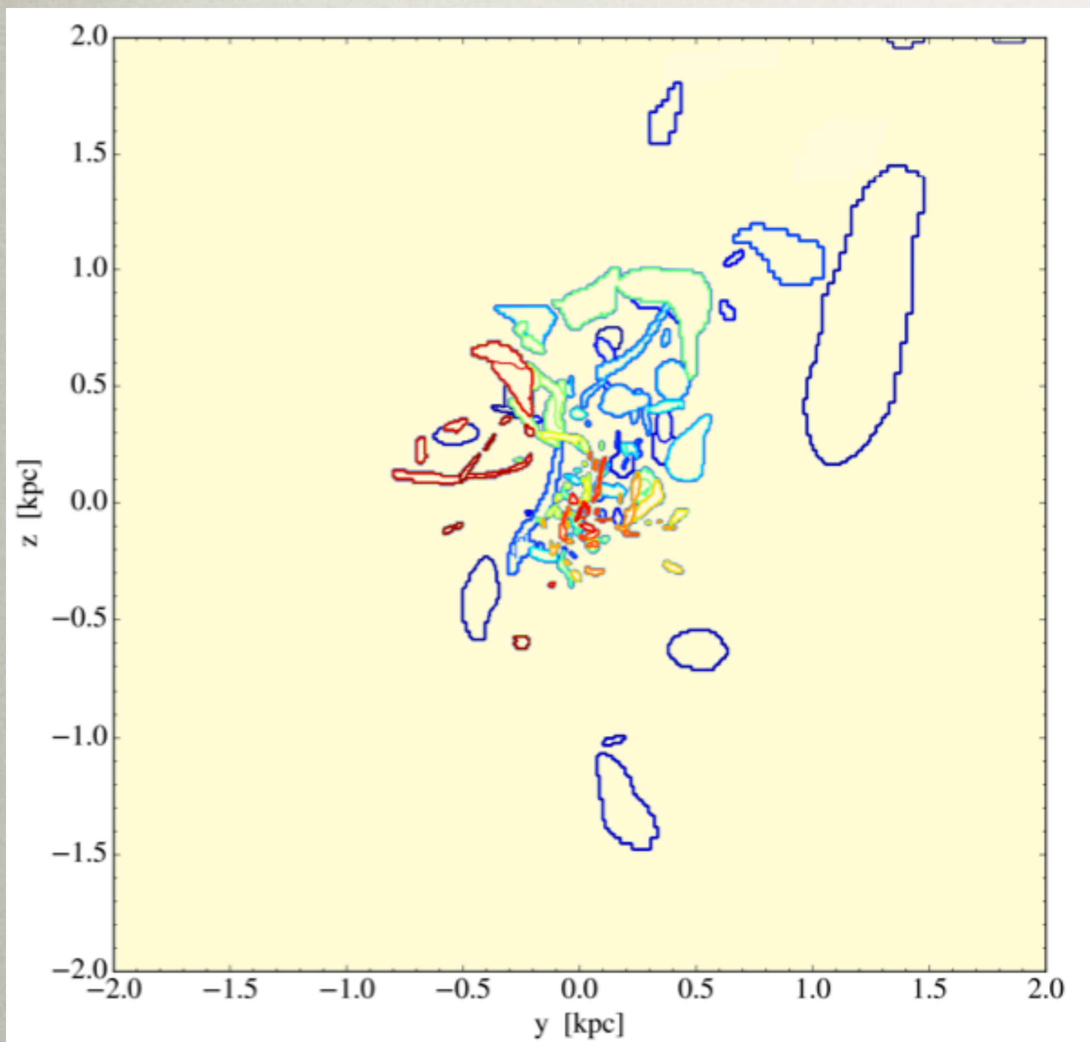
RGB surface density: plasma (blue), warm gas (red), cold gas (green)

Since 2012, CCA has been corroborated by several independent observational and theoretical/simulation studies: e.g., Voit & Donahue 2015, Voit 2015a,b,c, 2016; Werner+2014; David+2014, Li & Bryan 2014, 2015; Wong+2014; Russell+2015; Valentini & Brighenti 2015; Yang+2015-2016; Meece+2016; Tremblay+2015, 2016; Prasad+2016; David+2017; etc.

MULTIPHASE CCA

DYNAMICS

MG+17



- leaf clouds via clump finder algorithm
- network of condensed structures
- key for AGN obscuration/unification models (BLR, NLR)
- **angular momentum mixing/cancellation via inelastic collisions**

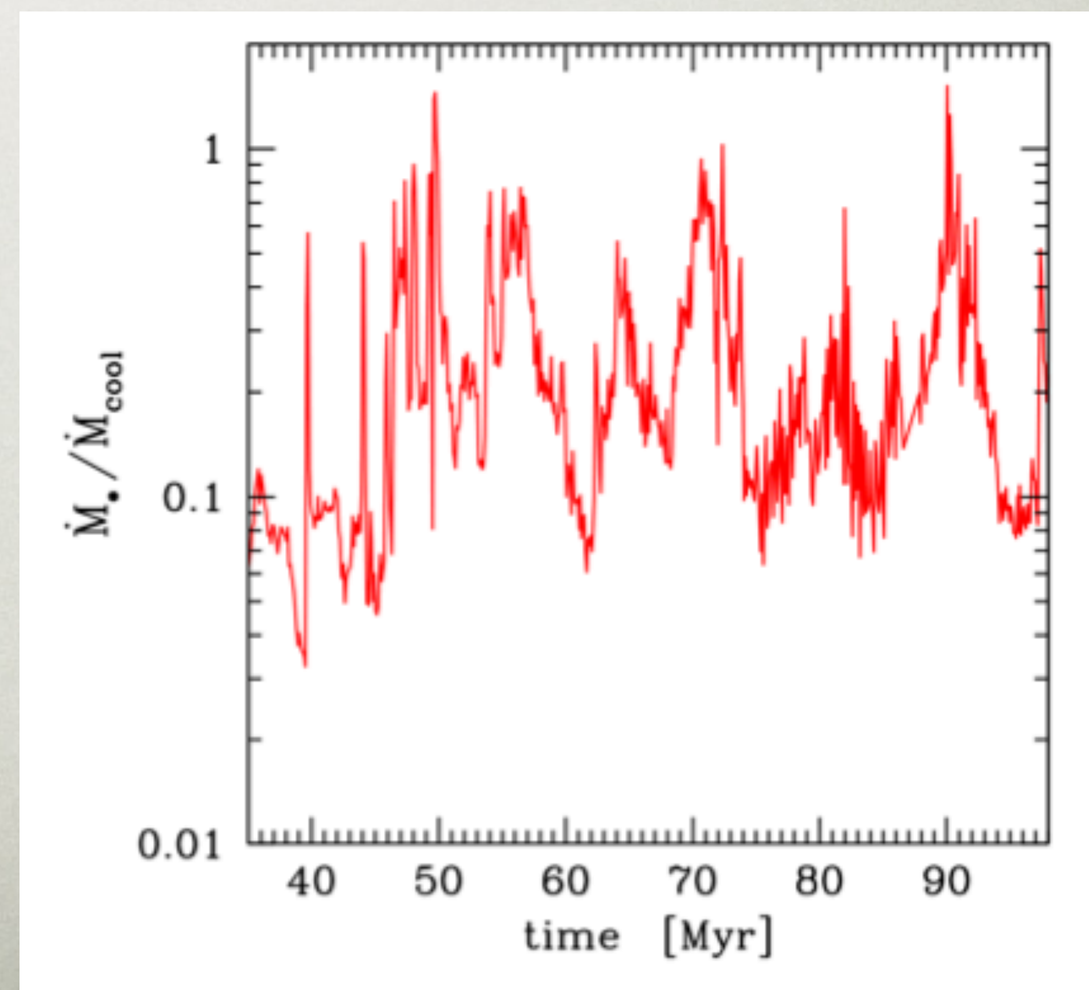
can be modeled as quasi-spherical viscous accretion:

$$\lambda_c \equiv \frac{1}{n_c\,\pi(2\,r_c)^2} = \frac{1}{3}\frac{r_c}{f_V} \simeq 88^{+262}_{-67}\ \mathrm{pc}$$ mean free path

$$\nu_c \equiv \sigma_v\,\lambda_c \simeq 4.5^{+13.3}_{-3.1} \times 10^{27}\ \mathrm{cm^2\ s^{-1}}$$ effective collisional viscosity

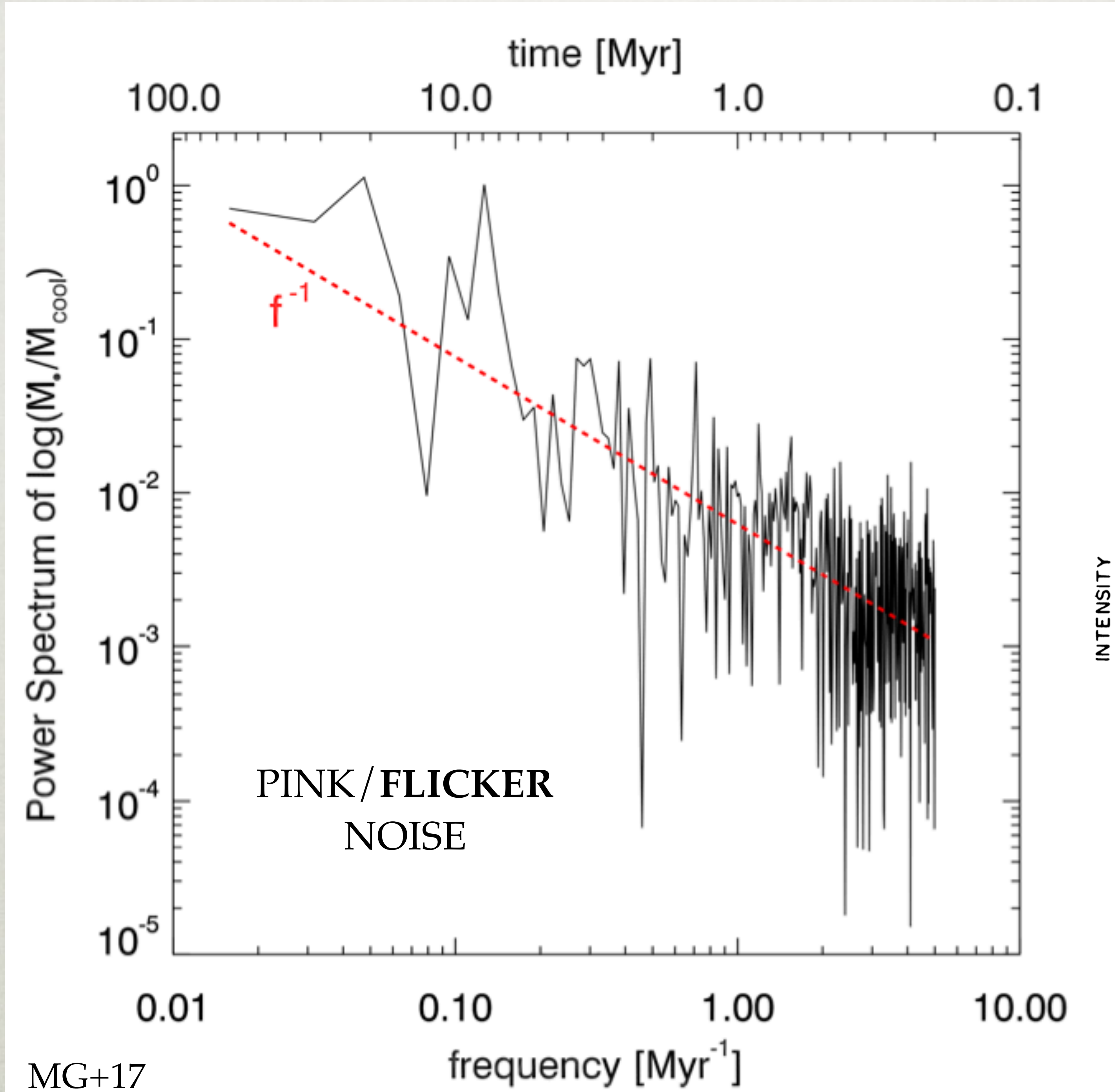
$$\dot{M}_\bullet = 4.8 \times 10^{-3}\,\nu_c \simeq 0.3^{+0.9}_{-0.2}\ \mathrm{M_\odot\ yr^{-1}}$$ average inflow rate (for massive ETG)

recurrent 2 dex boost in accretion rate



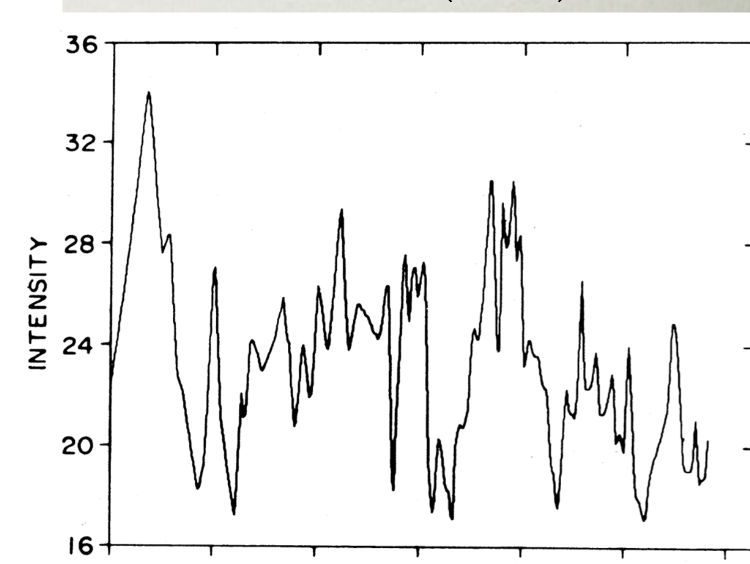
MULTIPHASE CCA

VARIABILITY



can explain ubiquitous rapid AGN and HMXBs variability

beautiful case: 3C273
Press (1978)



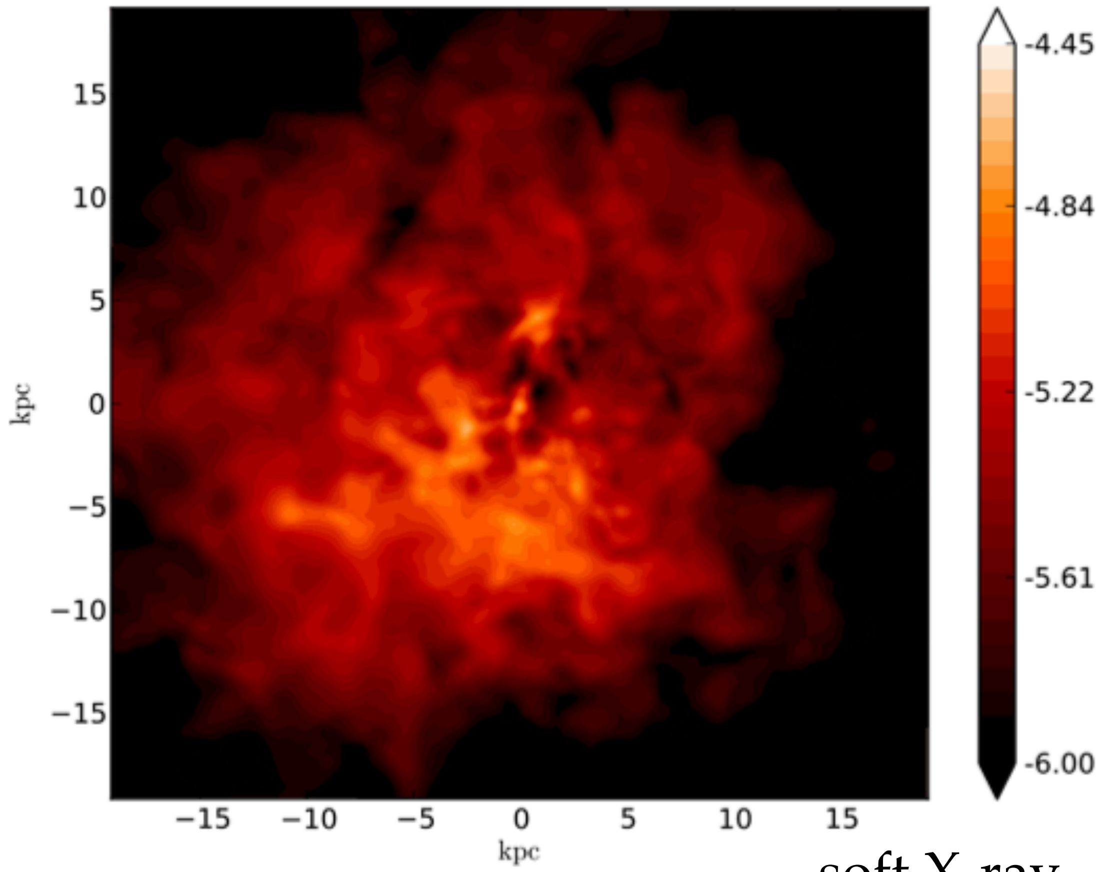
see MG16 for detailed list of variable AGN

constant variance per log interval => large self-similar variability on different timescales

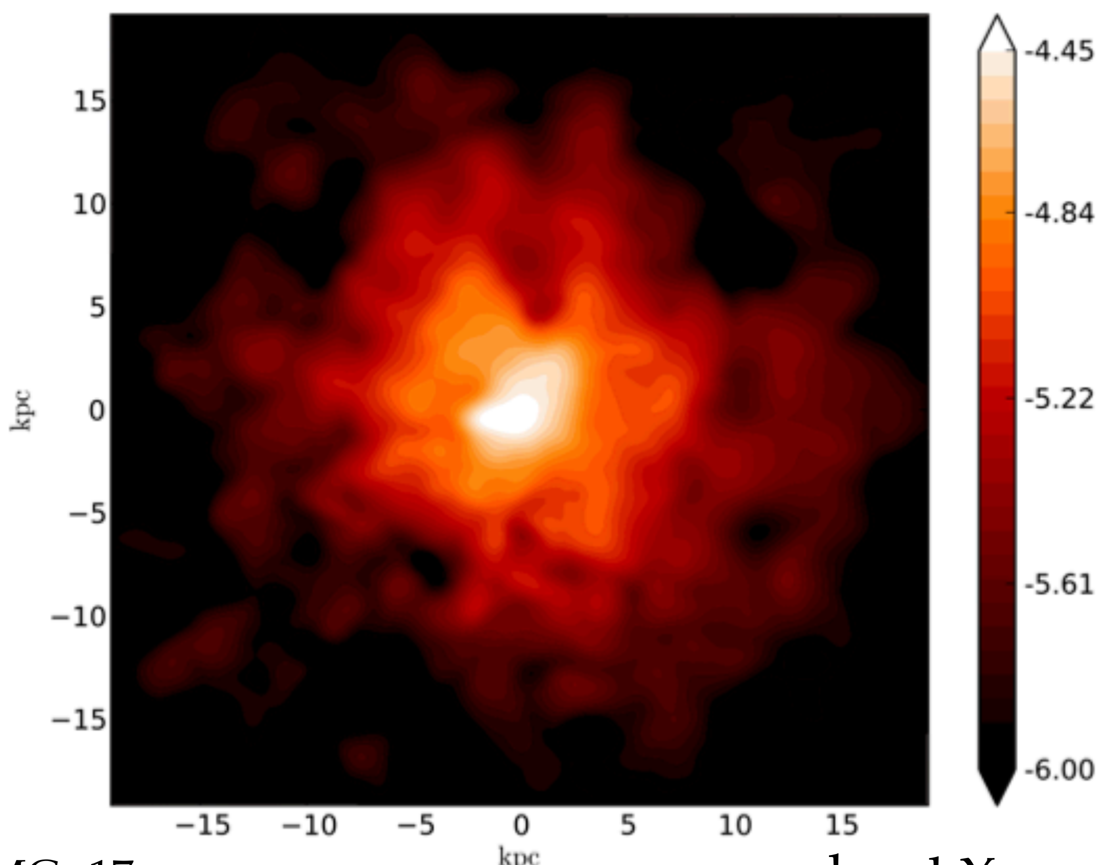
characteristic of <u>fractal and chaotic phenomena</u>

(quasars, sunspots, meteorological data, heart beat rhythms, neural activity, stock market, ...)

MULTIPHASE CCA:
1. HOT PLASMA

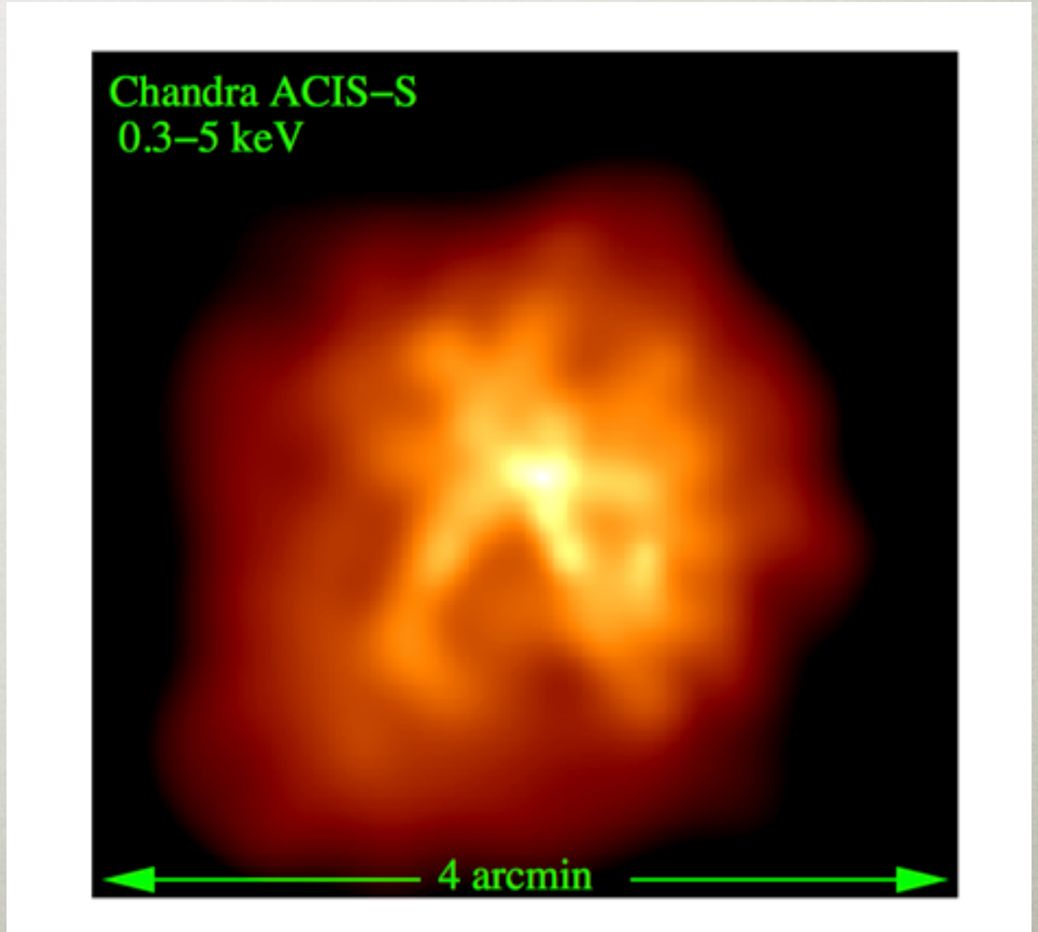


soft X-ray

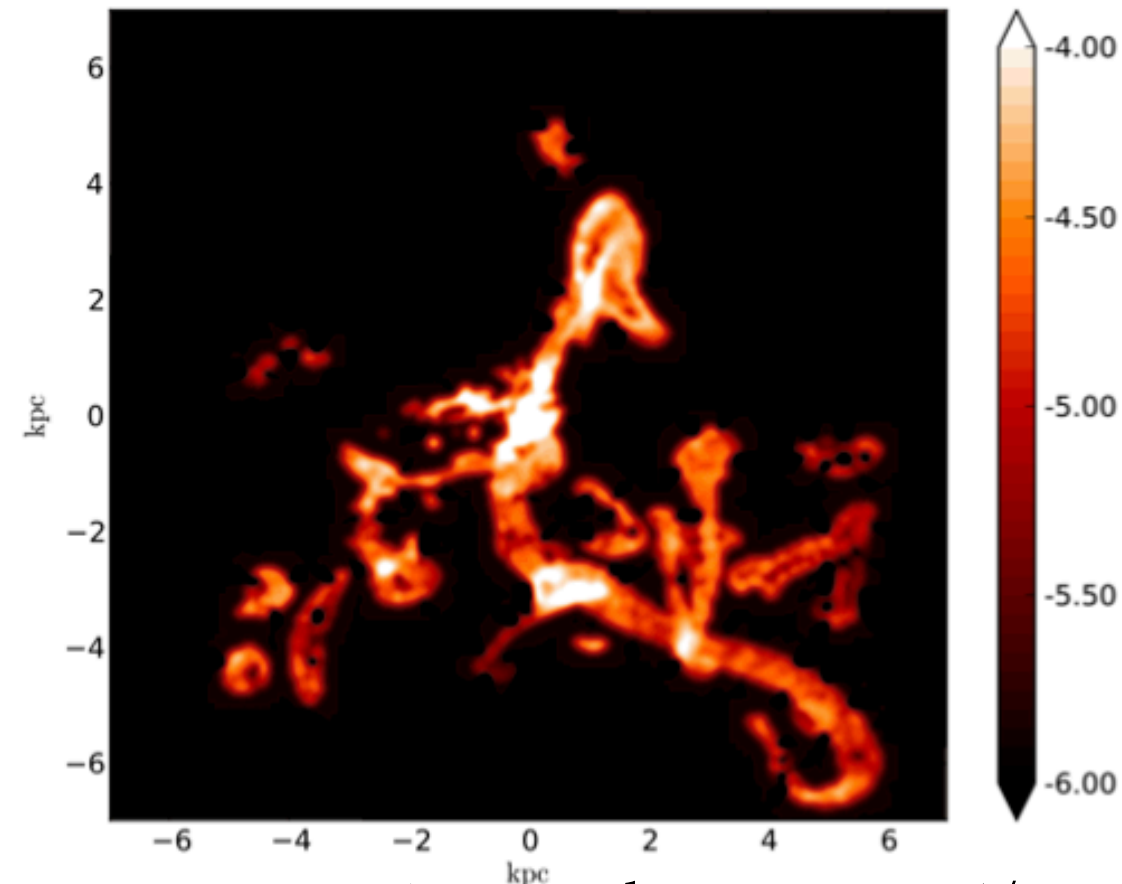


MG+17 hard X-ray

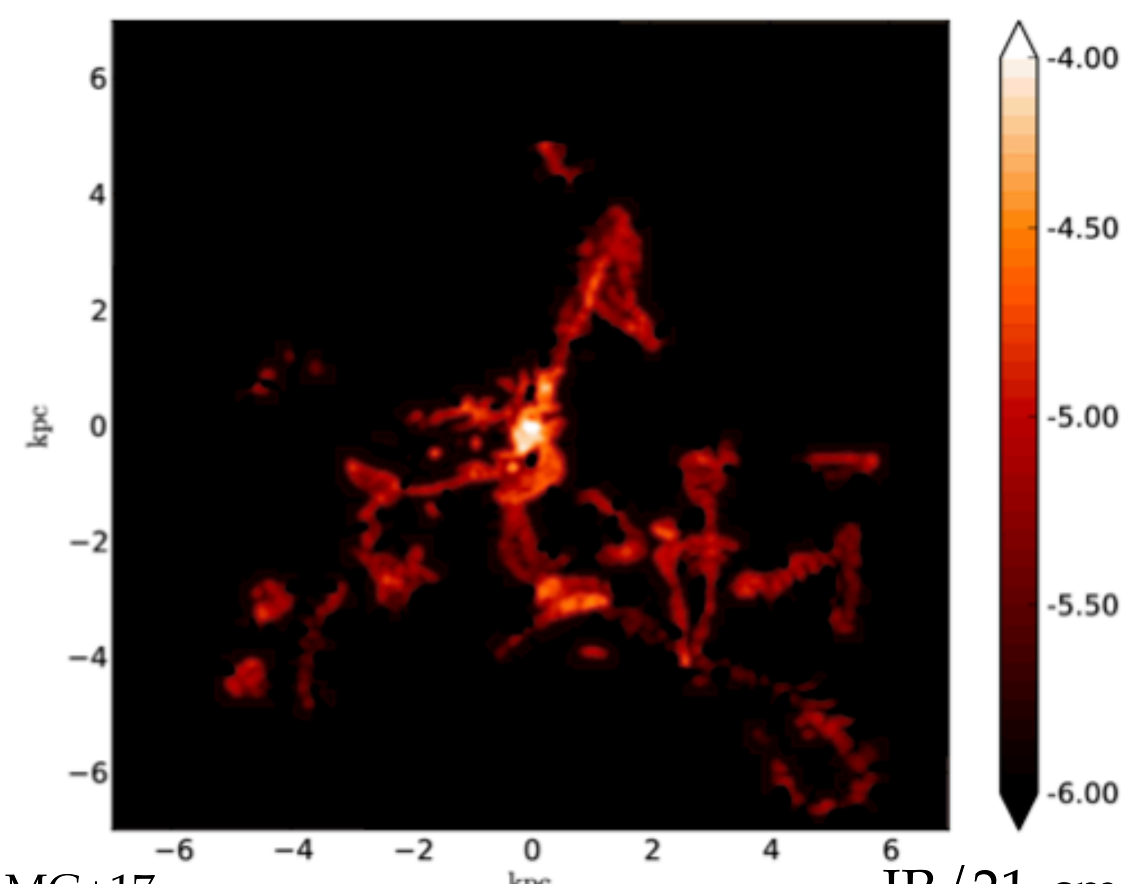
- turbulent eddies imprint => naturally create “cavities”/”fronts”
- X-ray “filaments” start to appear below 0.5 keV
- weak subsonic turbulence is enough to trigger CCA



Buote+04



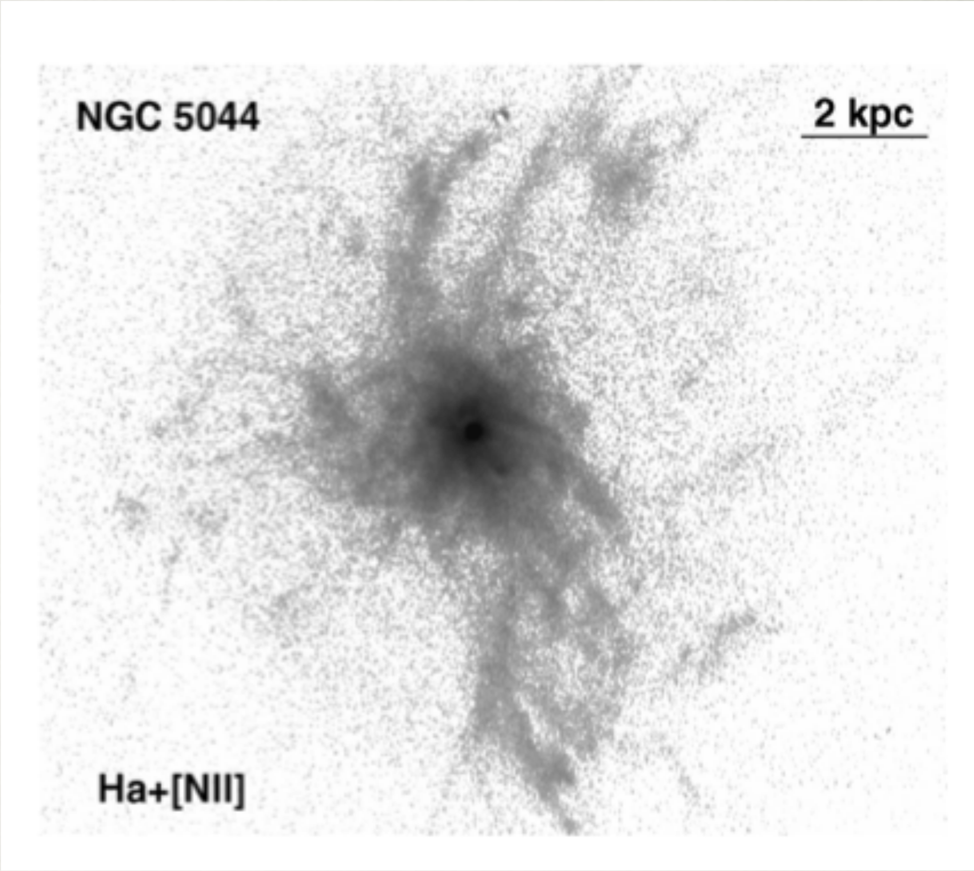
ionized warm phase optical/UV



MG+17 IR/21-cm

neutral warm phase

Werner+14: SOAR



- more reliable thermal instability/ **multiphase condensation criterium**:

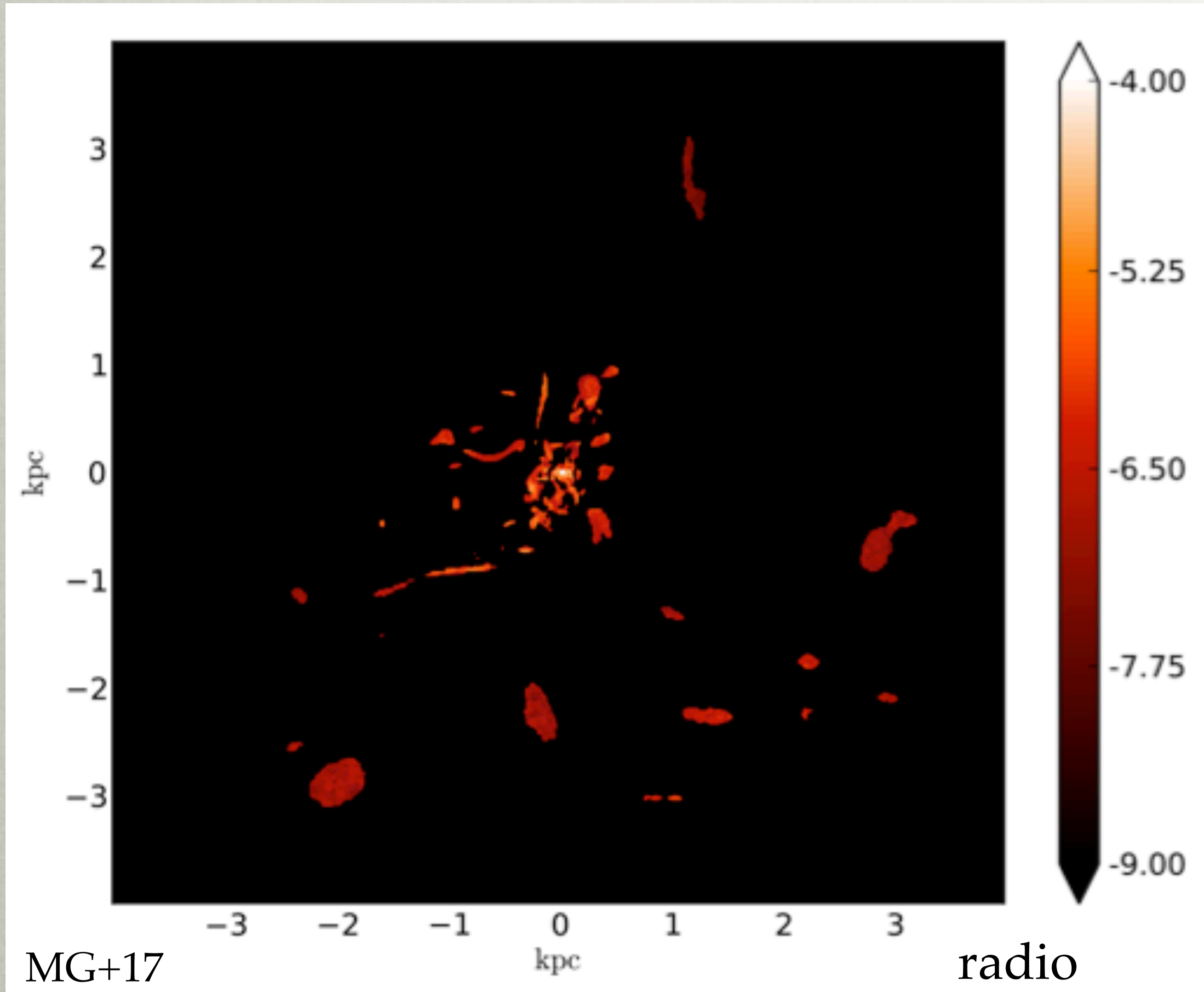
$$t_{\rm cool}(l')/t_{\rm eddy}(l') \equiv \sigma_v(l')/v_{\rm cool}(l') \lesssim 1$$

leads to a condensation radius of 7 kpc

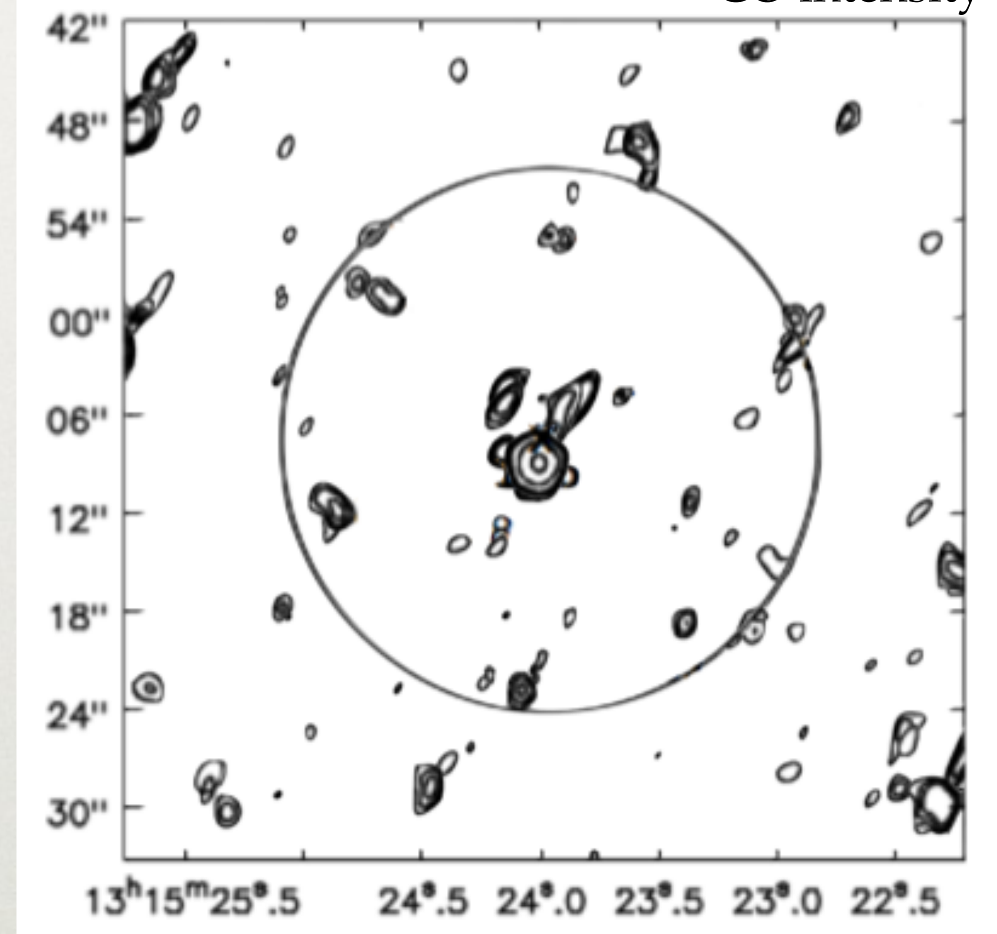
- **top-down** condensation: ionized skin envelops neutral filaments
- **filaments** naturally form out of the interacting sheets between large-scale eddies

MULTIPHASE CCA: 2. WARM PHASE

MULTIPHASE CCA:
3. COLD/MOLECULAR PHASE

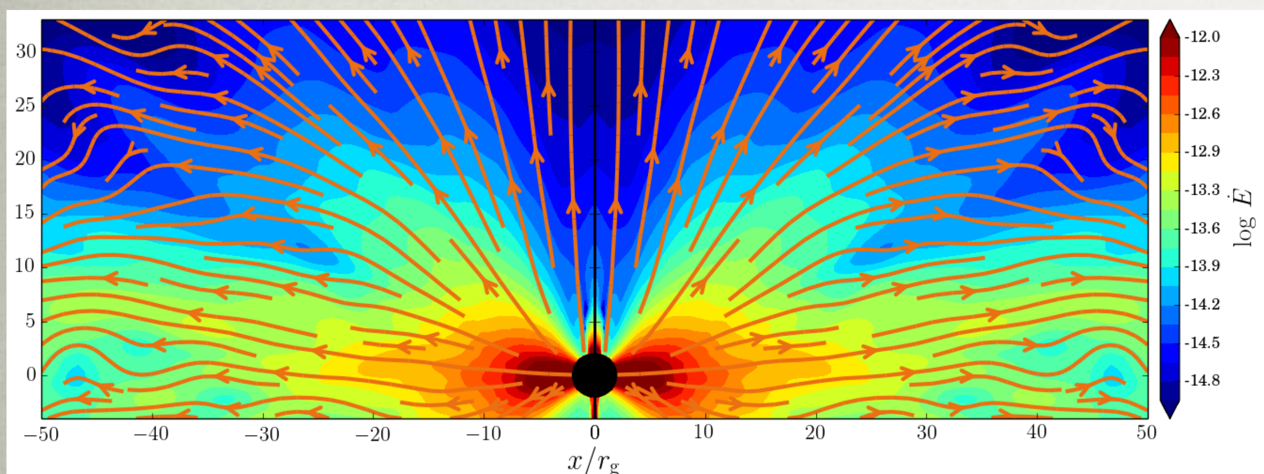


David+14-17: ALMA
CO intensity



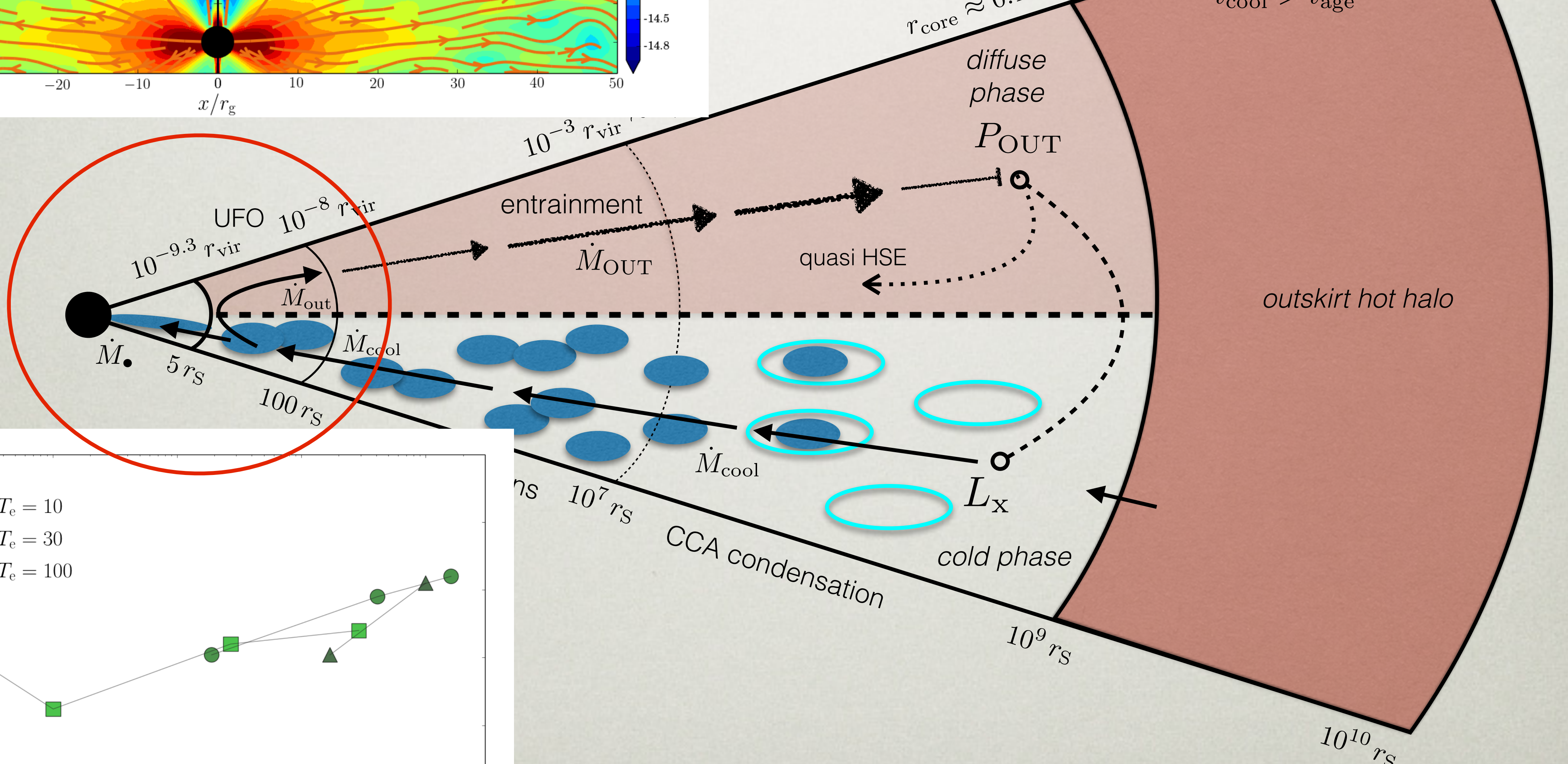
- molecular clouds typically combine in GMAs (**giant molecular associations**), up to 100 pc with surface density ranging 50-200 Msun/pc^2, as found by ALMA
- **cospatial** with warm phase and soft X-ray plasma, though more compact
- as for the warm gas, ensemble velocity dispersion inherited by turbulence (150 km/s), albeit internal dispersion is about 1 dex lower (turbulence cascade) => **dynamically supported** (virial parameter >> 1)
- r < 100 pc **funneling** of clouds with velocities 100s km/s (LOS absorption features: A2597, NGC 5044; Tremblay+16)

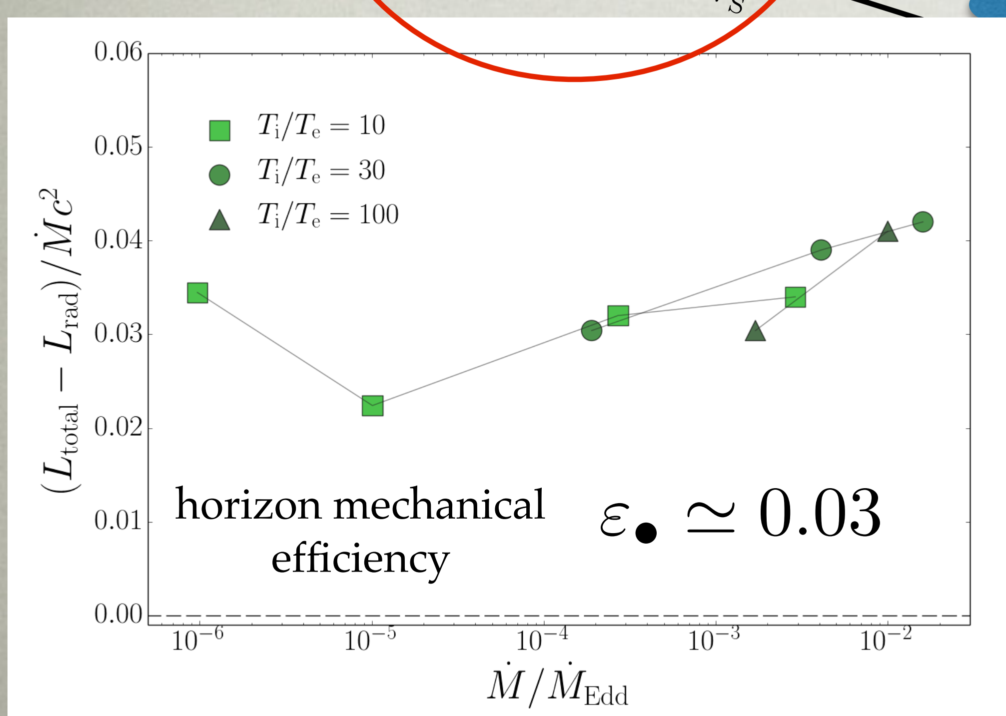
AGN FEEDBACK:
MICRO SCALE - GR-RMHD SIMS



UFO = Ultra-Fast Outflows

magnetically and thermally driven





horizon mechanical efficiency $\varepsilon_\bullet \simeq 0.03$

Sadowski & Gaspari 2017

General relativistic, radiative, MHD sims

thick accretion flow and nearly null BH spin (due to chaotic accretion)

UNIFYING THE MICRO AND MACRO EFFICIENCY

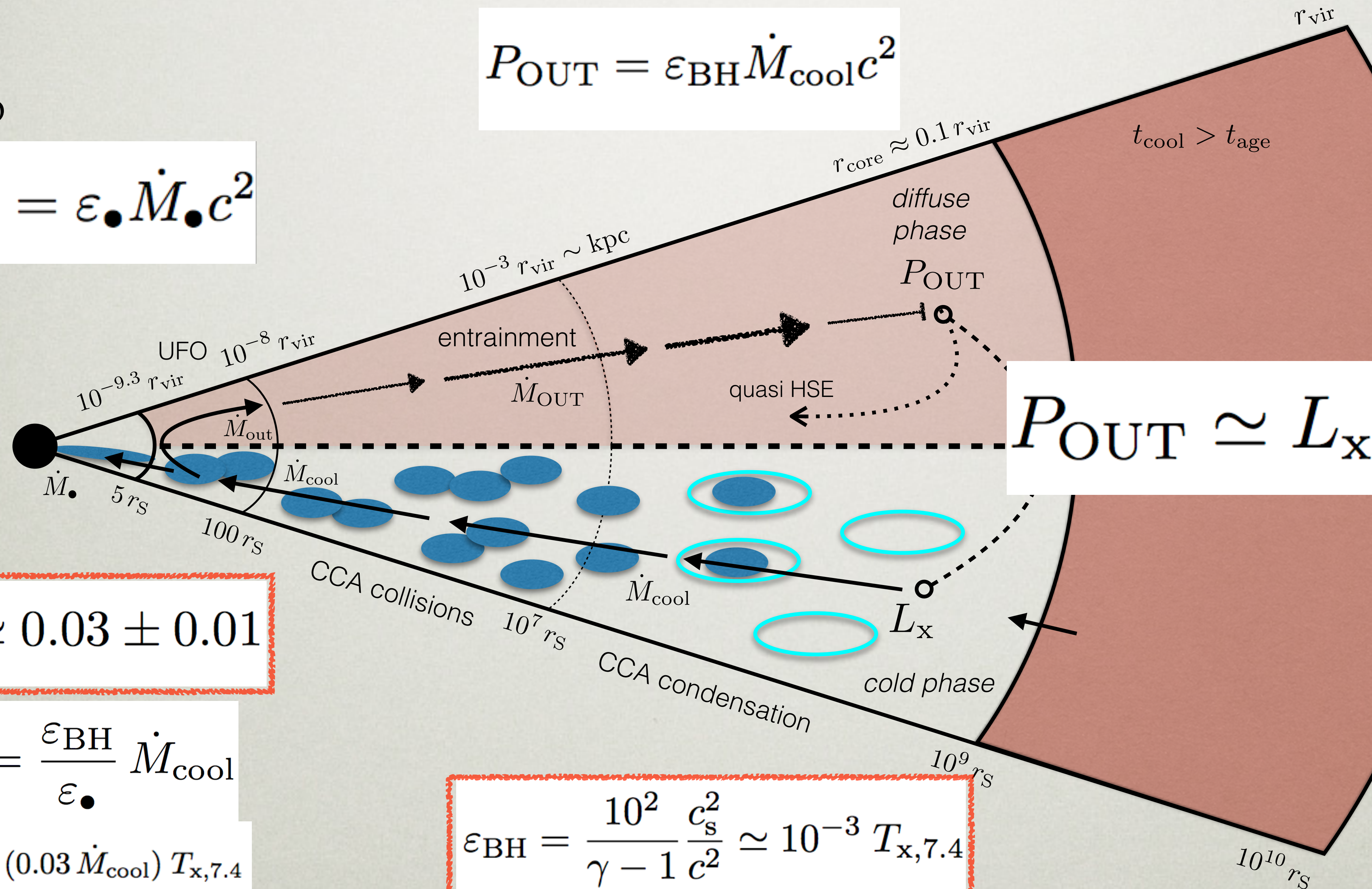
Gaspari & Sadowski 2017

MACRO

$$P_{\rm OUT} = \varepsilon_{\rm BH} \dot{M}_{\rm cool} c^2$$

MICRO

$$P_{\rm out} = \varepsilon_\bullet \dot{M}_\bullet c^2$$



loop has frequency $t_{\rm cool}^{-1}$

$$\varepsilon_\bullet \simeq 0.03 \pm 0.01$$

$$\dot{M}_\bullet = \frac{\varepsilon_{\rm BH}}{\varepsilon_\bullet}\, \dot{M}_{\rm cool}$$

$$\dot{M}_\bullet \simeq (0.03\, \dot{M}_{\rm cool})\, T_{\rm x,7.4}$$

most of the mass ejected

$$\varepsilon_{\rm BH} = \frac{10^2}{\gamma - 1}\frac{c_{\rm s}^2}{c^2} \simeq 10^{-3}\, T_{\rm x,7.4}$$

$$\dot{M}_{\rm cool} \simeq 10^{-2}\, \dot{M}_{\rm CF} \simeq 6.7 \times 10^{-3}\, \frac{L_{\rm x}}{c_{\rm s,x}^2}$$

CCA X-ray spectrum

$$L_{\rm x} \simeq 6 \times 10^{43}\, (T_{\rm x}/2.2\,{\rm keV})^3\ {\rm erg\, s^{-1}}$$

or any other scaling relation

UNIFYING THE MICRO AND MACRO OUTFLOWS

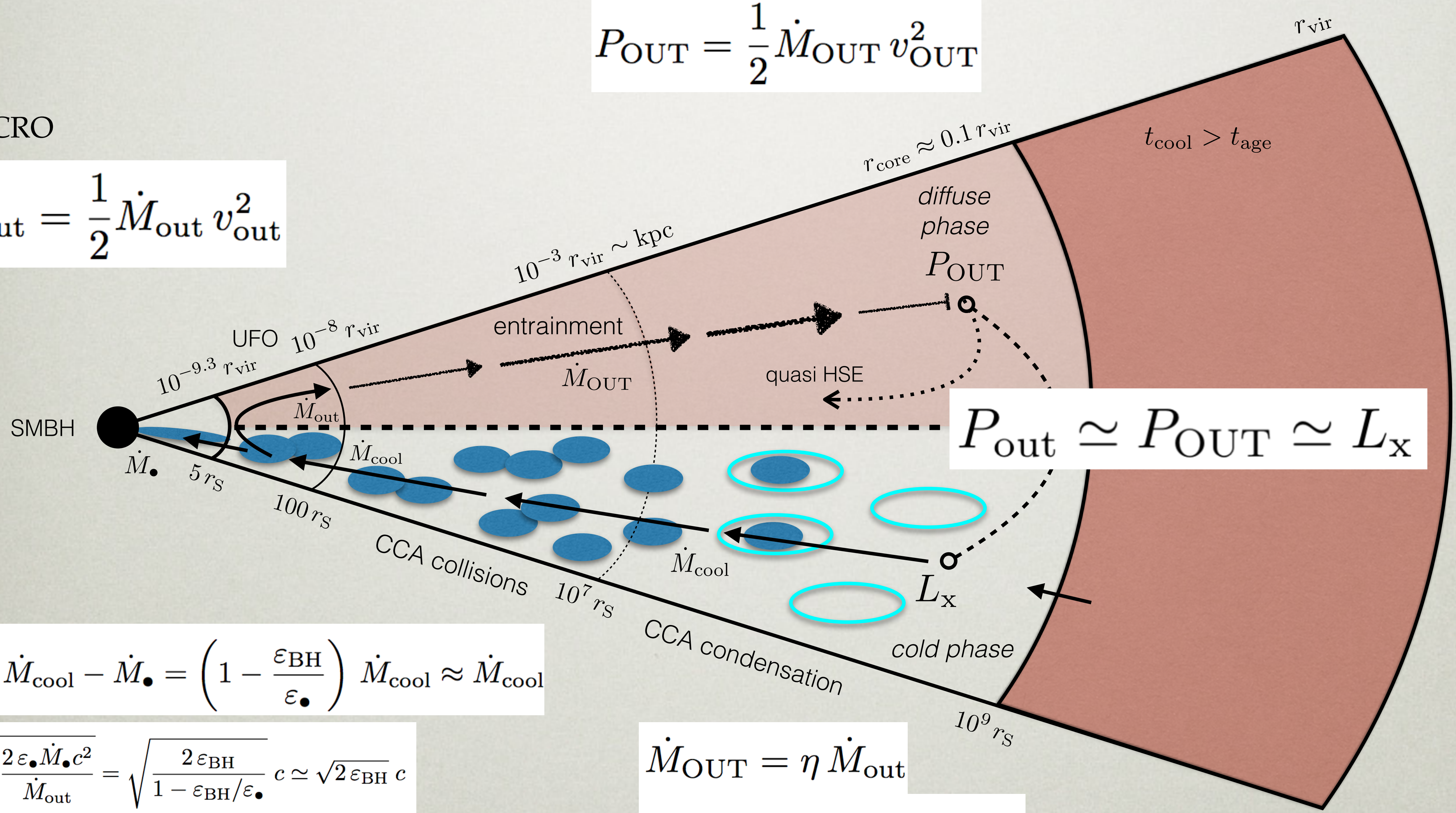
Gaspari & Sadowski 2017

MACRO

$$P_{\rm OUT} = \frac{1}{2}\dot{M}_{\rm OUT}\, v_{\rm OUT}^2$$

MICRO

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



$$P_{\rm out} \simeq P_{\rm OUT} \simeq L_{\rm x}$$

$$\dot{M}_{\rm out} = \dot{M}_{\rm cool} - \dot{M}_\bullet = \left(1 - \frac{\varepsilon_{\rm BH}}{\varepsilon_\bullet}\right)\dot{M}_{\rm cool} \approx \dot{M}_{\rm cool}$$

$$v_{\rm out} = \sqrt{\frac{2\,\varepsilon_\bullet \dot{M}_\bullet c^2}{\dot{M}_{\rm out}}} = \sqrt{\frac{2\,\varepsilon_{\rm BH}}{1-\varepsilon_{\rm BH}/\varepsilon_\bullet}}\, c \simeq \sqrt{2\,\varepsilon_{\rm BH}}\, c$$

$$\simeq (1.4\times10^4\ {\rm km\,s^{-1}})\ T_{\rm x,7.4}^{1/2}$$

$$\dot{M}_{\rm OUT} = \eta\, \dot{M}_{\rm out}$$

$$\dot{M}_{\rm OUT} = \Omega\, r^2\, \rho(r)\, v_{\rm OUT}(r)$$

$$v_{\rm OUT} = \sqrt{\frac{2P_{\rm OUT}}{\dot{M}_{\rm OUT}}} = \eta^{-1/2}\, v_{\rm out}$$

PROPERTIES OF MACRO AGN OUTFLOWS

@ intermediate/kpc scale:

IONIZED OUTFLOWS

$v_{\rm OUT,ion} \approx$ a few $10^3\,{\rm km\,s^{-1}}$

$\dot{M}_{\rm OUT,ion} \approx 10{\rm s}\ {\rm M_\odot\,yr^{-1}}$

see X-ray data: Tombesi+12,13,16

NEUTRAL OUTFLOWS

$v_{\rm OUT,neu} \approx 10^3\,{\rm km\,s^{-1}}$

$\dot{M}_{\rm OUT,neu} \approx 100\ {\rm M_\odot\,yr^{-1}}$

see HI 21-cm data: Morganti+05,07,15, Teng+13

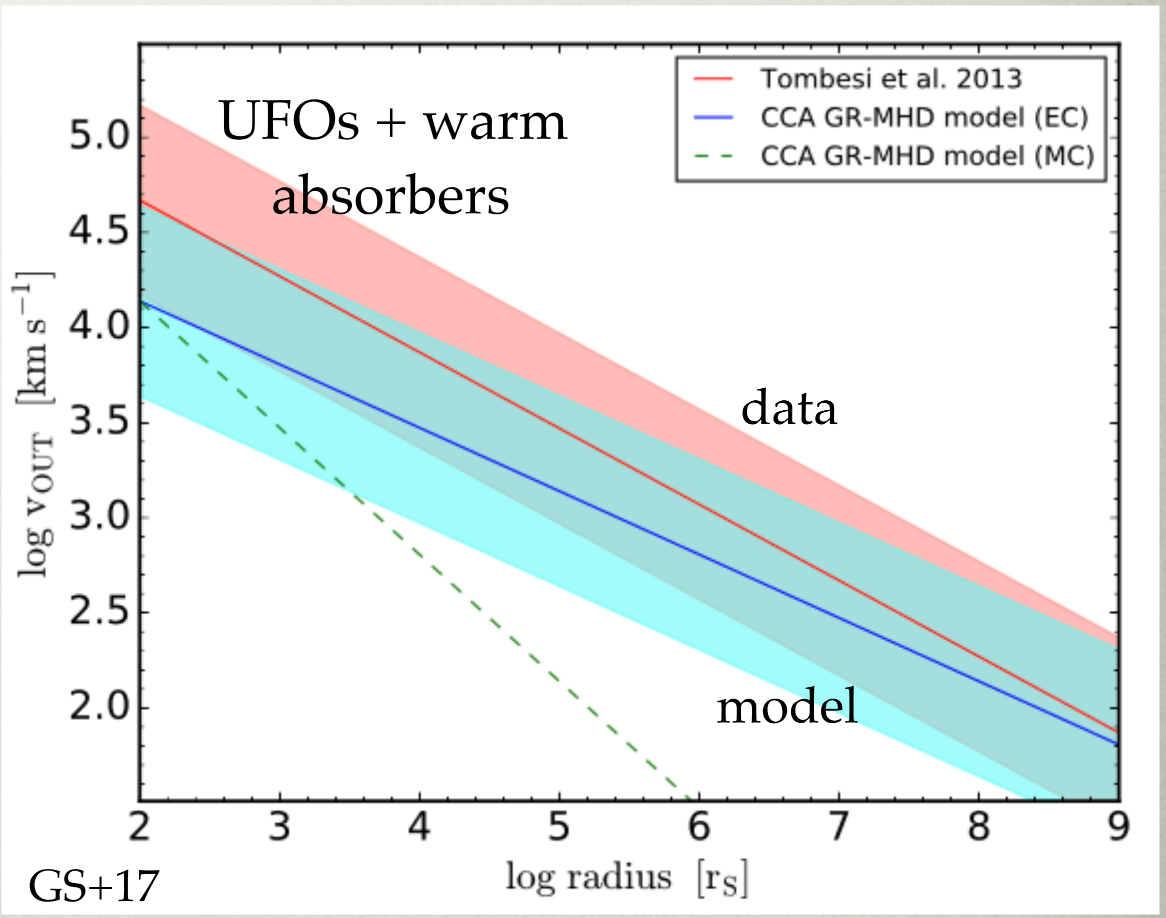
MOLECULAR OUTFLOWS

$v_{\rm OUT,mol} \approx 500\,{\rm km\,s^{-1}}$

$\dot{M}_{\rm OUT,mol} \approx$ several $100\ {\rm M_\odot\,yr^{-1}}$

see radio/CO data: Sturm+11, Cicone+14, Russell+14, Combes+15, Feruglio+15

Case study: X-ray AGN outflows



energy conserving outflow is important

AGN FEEDBACK UNIFICATION