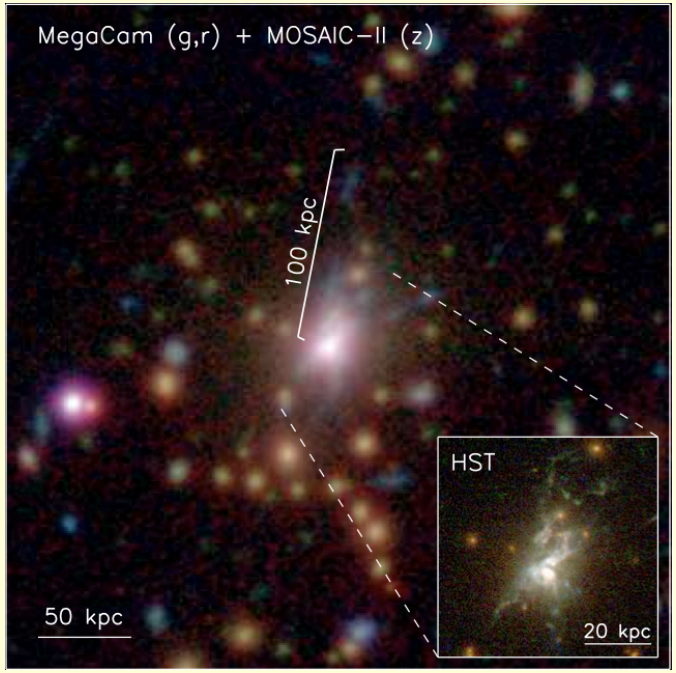
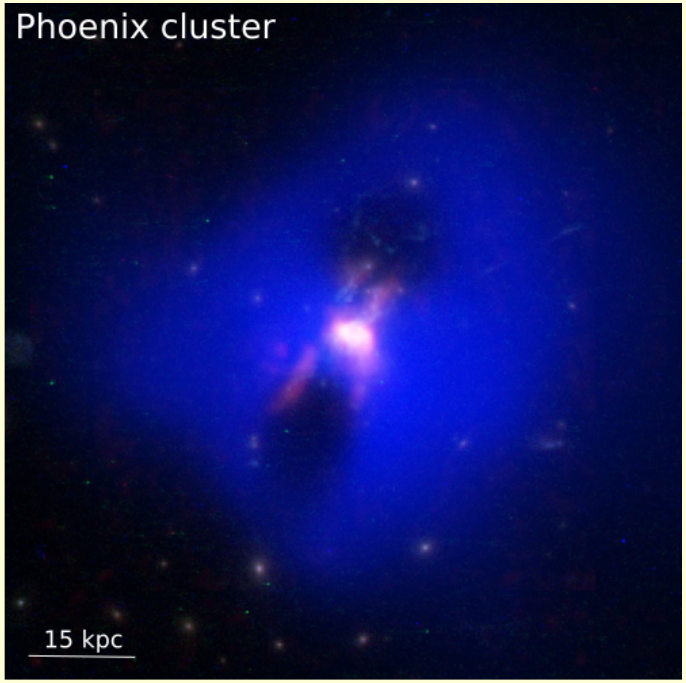
Thermally Unstable Cooling & Feedback Stimulated by Uplift





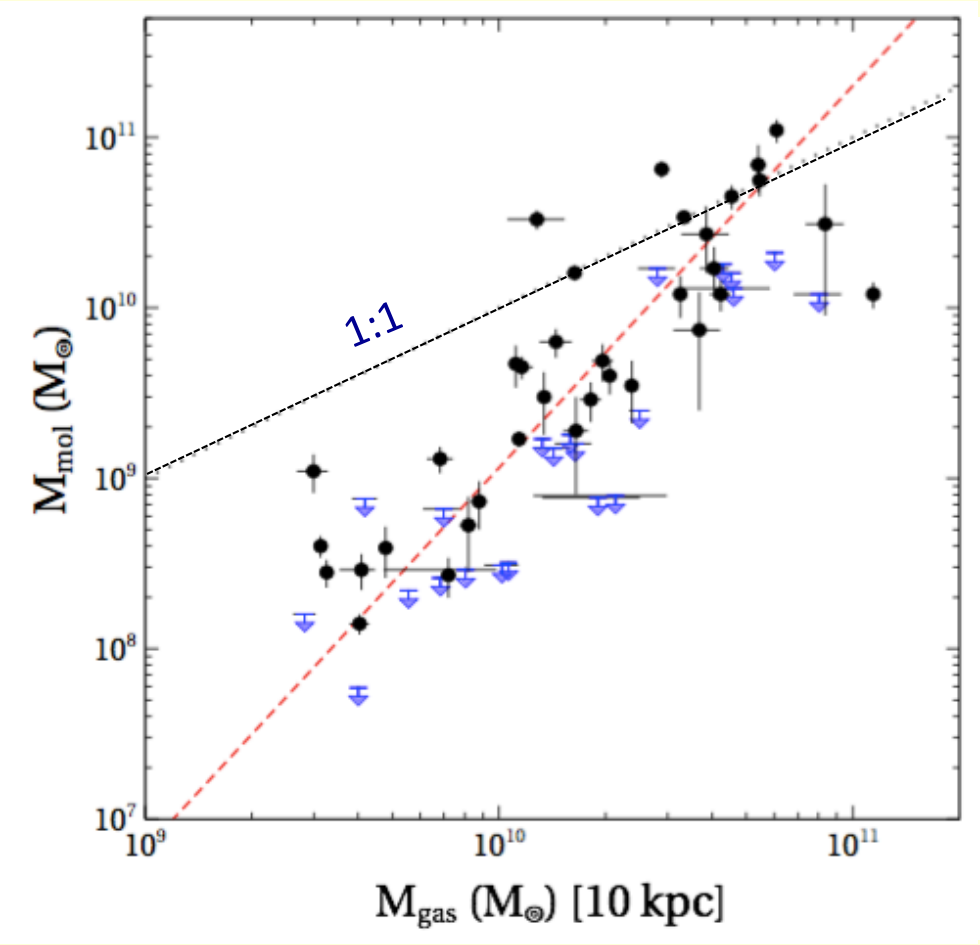
-- problems with precipitation models: $t_c/t_{ff} > 10$, role of t_{ff} observationally unclear
-- uplift of atmospheric gas stimulates cooling: $t_c/t_l < 1$

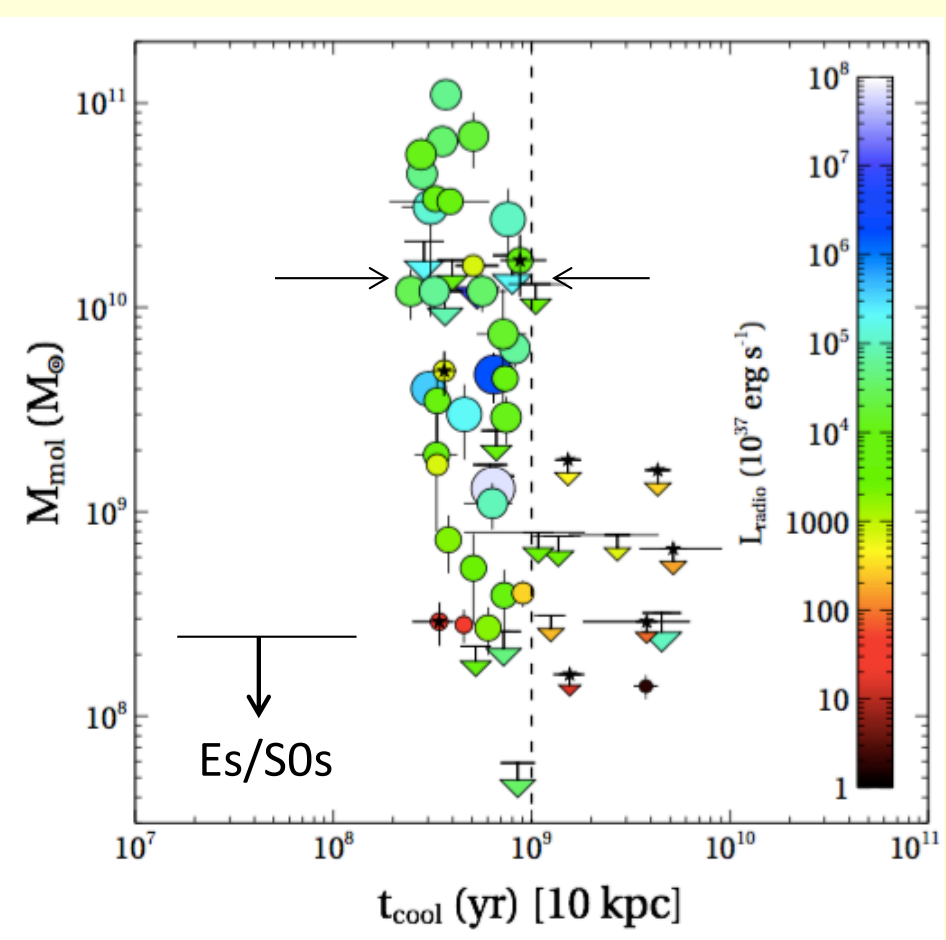
Brian McNamara (university of Waterloo)

Helen Russell (IOA), A. Edge, P. Nulsen, A. Fabian, …

Molecular Gas abundant, cooled from Hot Atmosphere

Pulido + 17, Edge 02



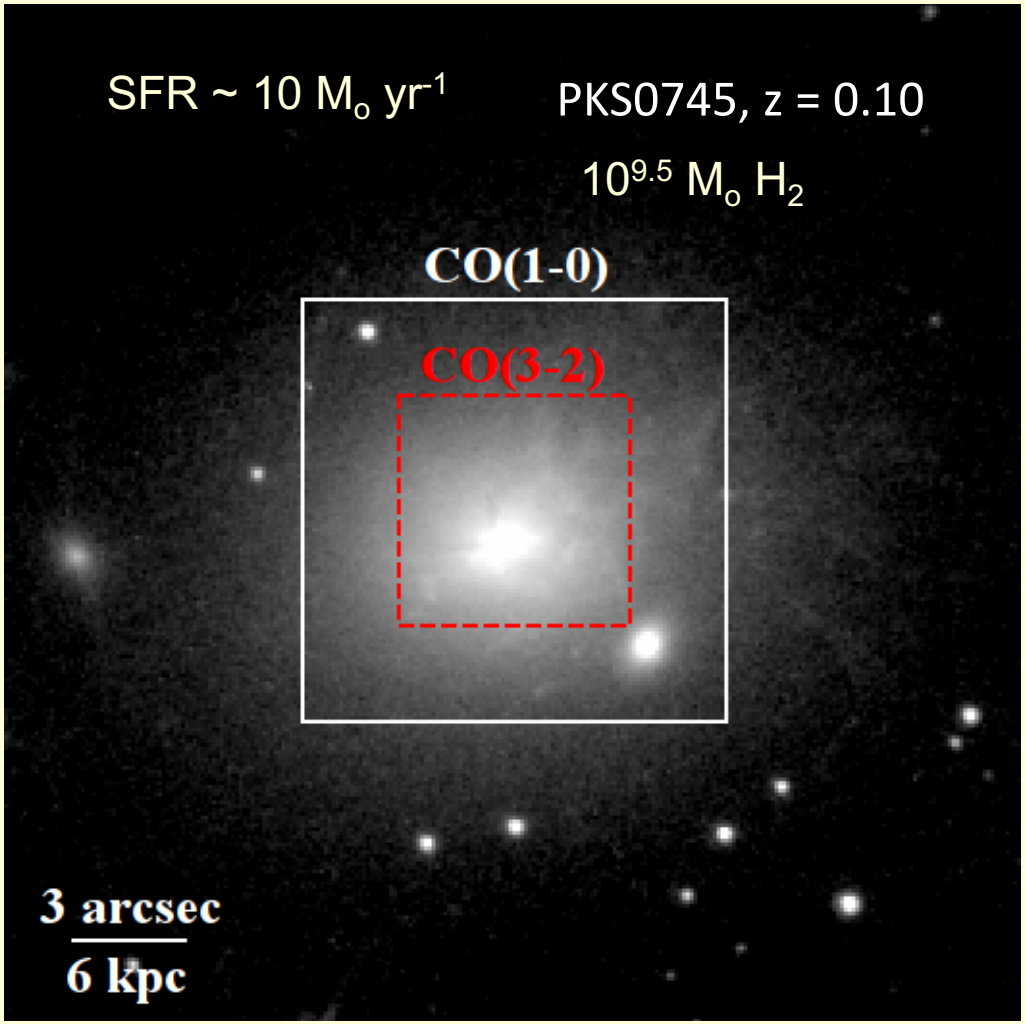


- Cold & hot mass correlated; easily supplied by hot phase
- Molecular gas >10^9 M_o occurs suddenly when t_c < 10^9 yr
  cooling time/entropy threshold (Rafferty + 08, Cavagnolo+08)

What do the molecular clouds look like?

Russell+14,16,17a,b, McNamara+ 14, David + 14,17, Tremblay+16, Vantyghem+17…

PKS0745 Central Galaxy



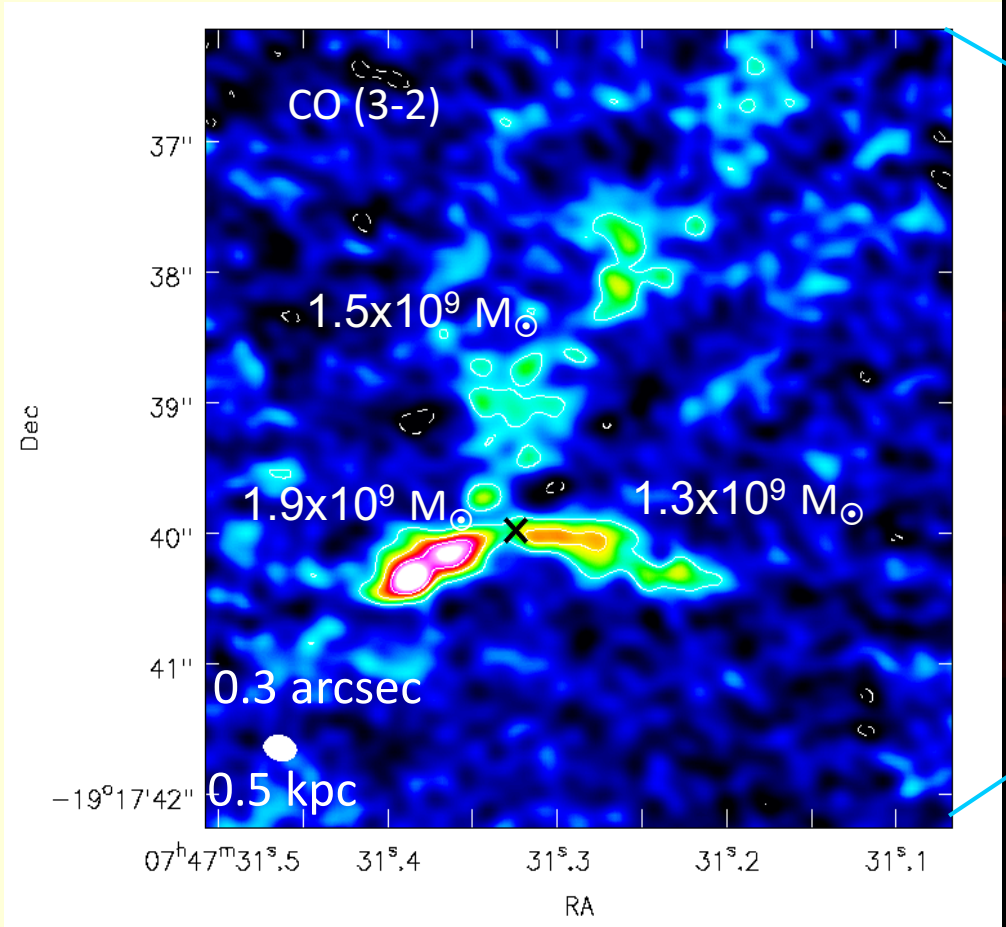
A1664, z = 0.13

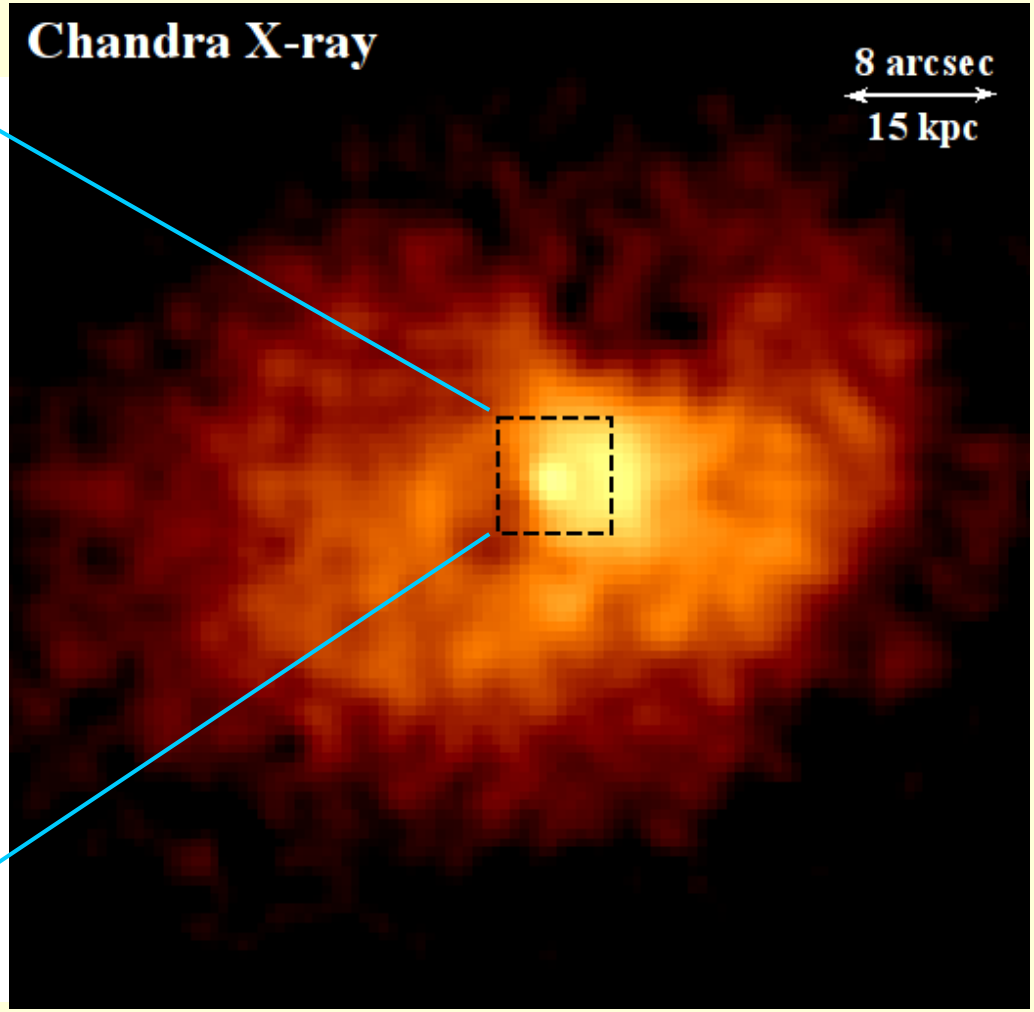
HST data: O'Dea et al. 2010

PKS0745: molecular filaments extend underneath X-ray cavities

- Uplift behind rising cavities?
- Gas falling back?

Russell + 16



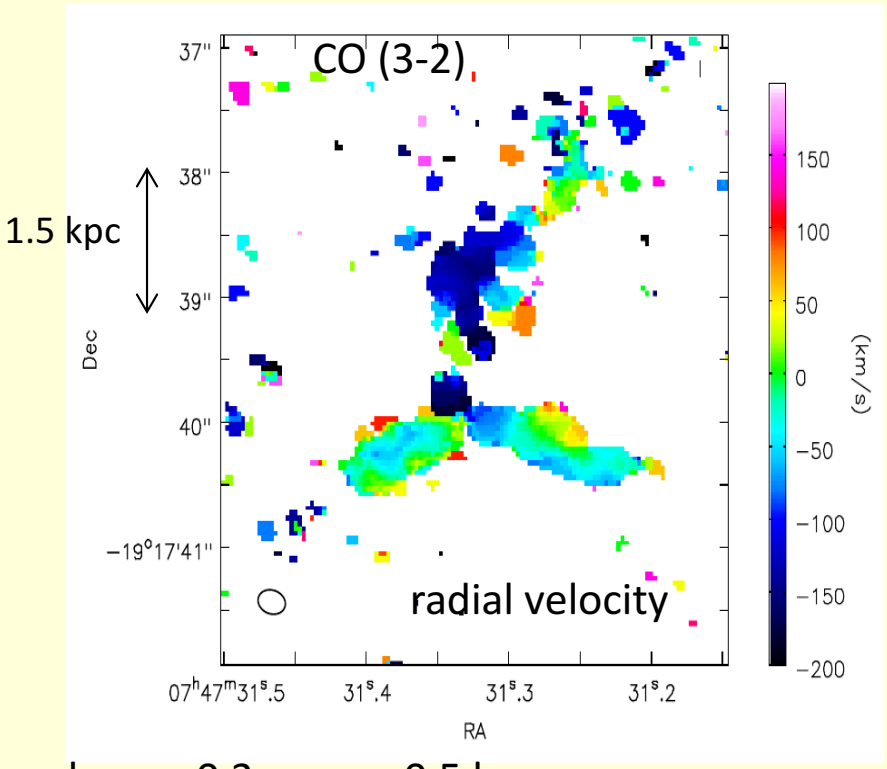


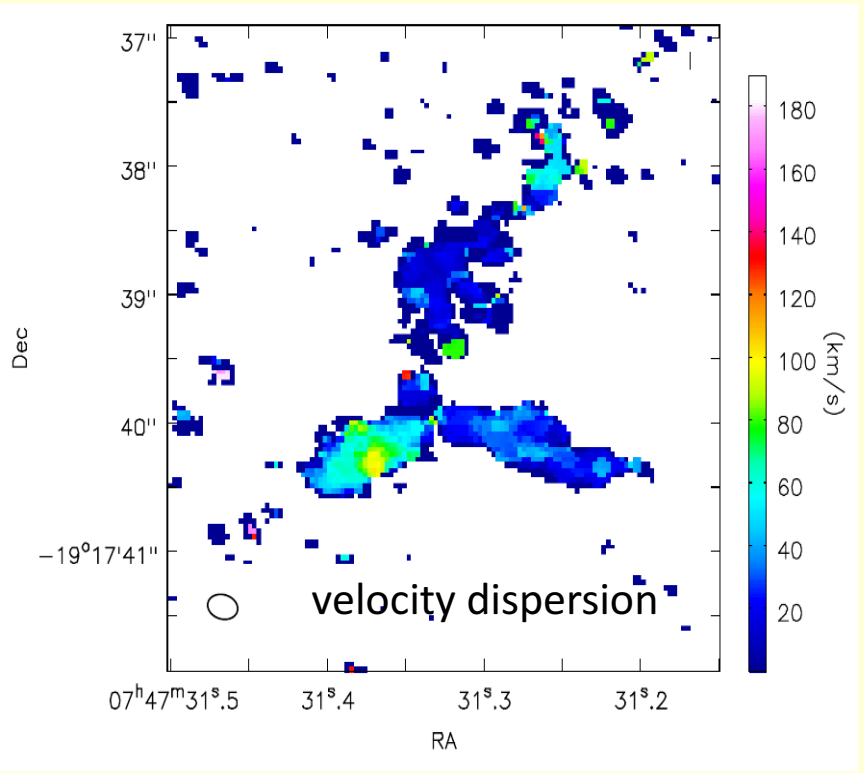
PKS0745: molecular gas in 3-5 kpc filaments, narrow velocity widths

- Modest radial velocities 100 km s^{-1}
- Narrow CO emission lines ~30-50 km s^{-1}
- No disk!
- Low turbulence in hot atmosphere

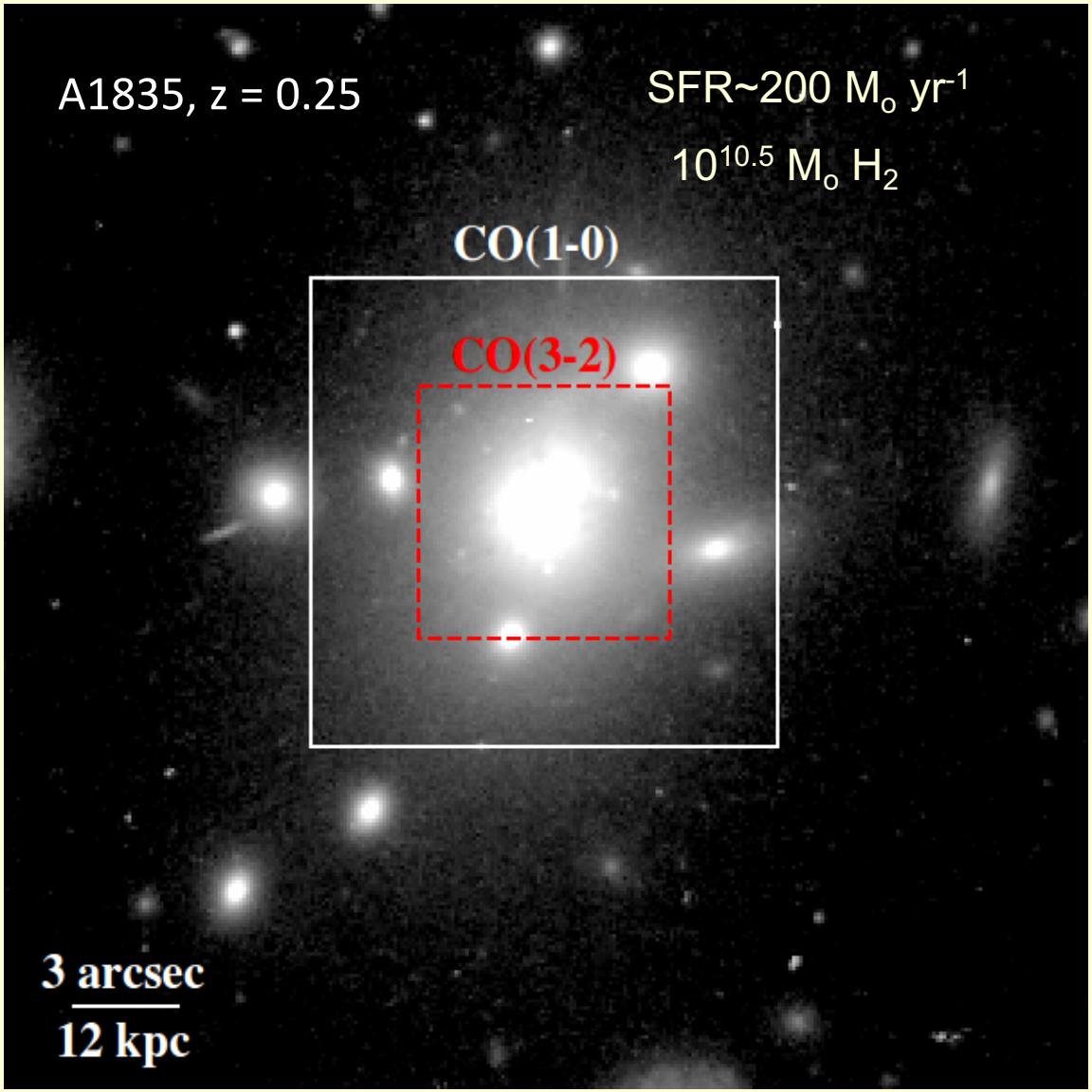
condensed rapidly
pinned to the ICM?
transient condensations?

Russell + 15





beam: 0.3 arcsec, 0.5 kpc

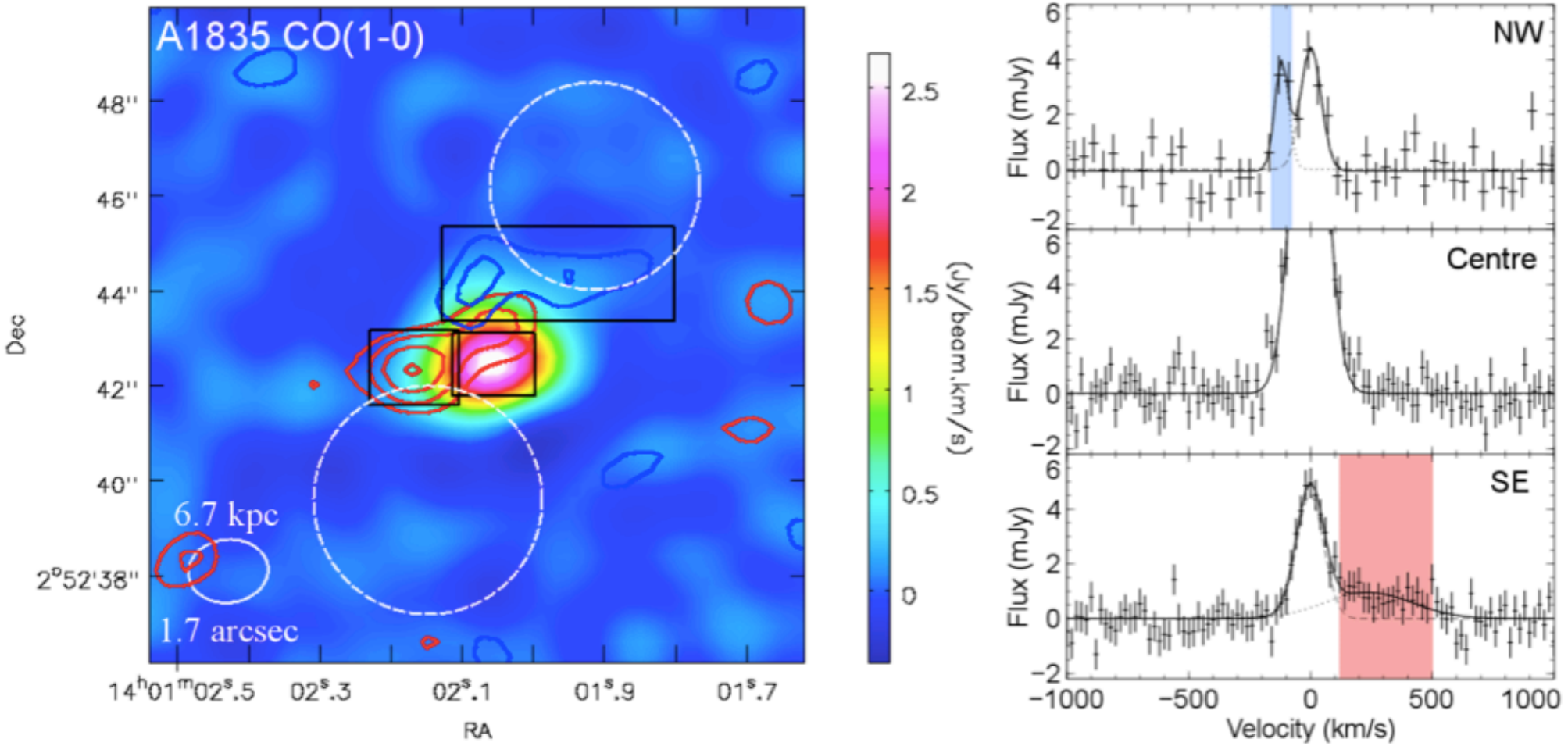


A1664, z = 0.13

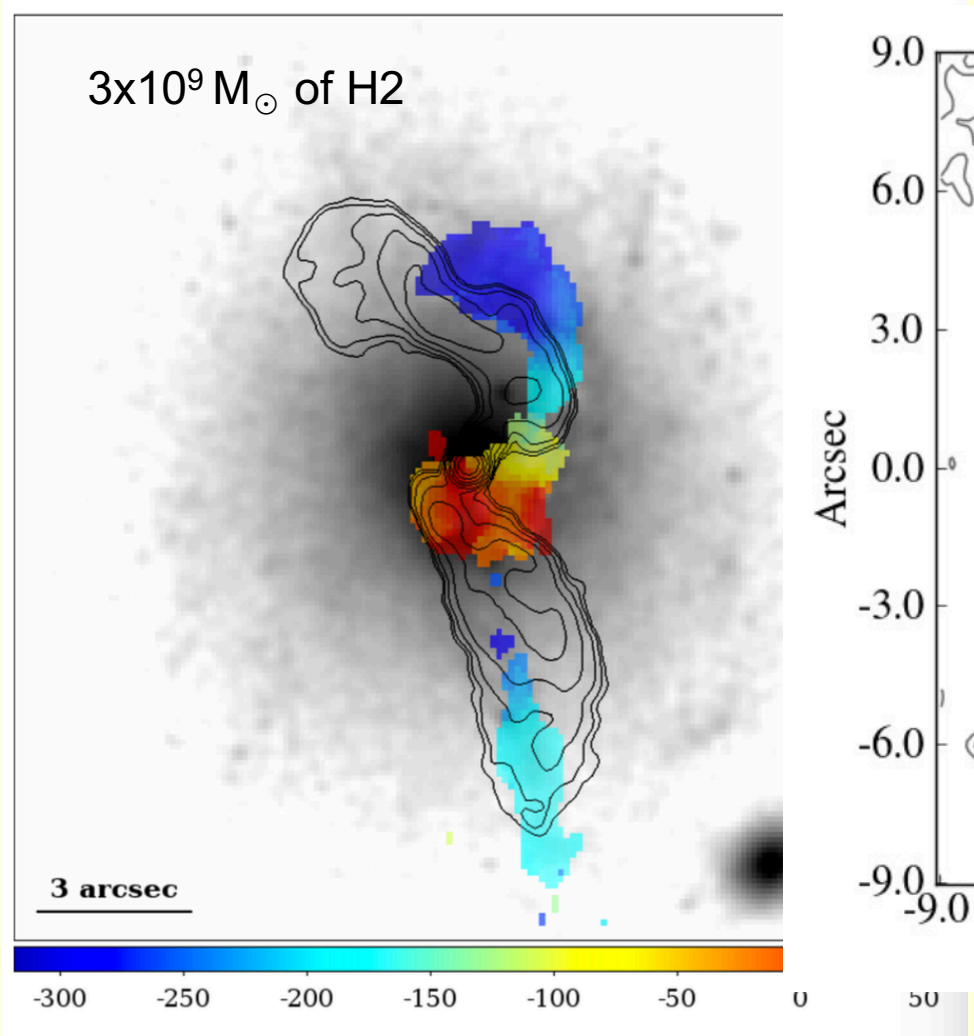
Abell 1835: radio driven outflow or *circulation flow*

- 200 - 480 km s^{-1} bipolar flow
- M_{flow} ~ 10^{10} $M_{\odot}$
- r = 5 -10 kpc
- Directed underneath X-ray cavities
- E_k~ 10^{58} erg < 1% of jet energy

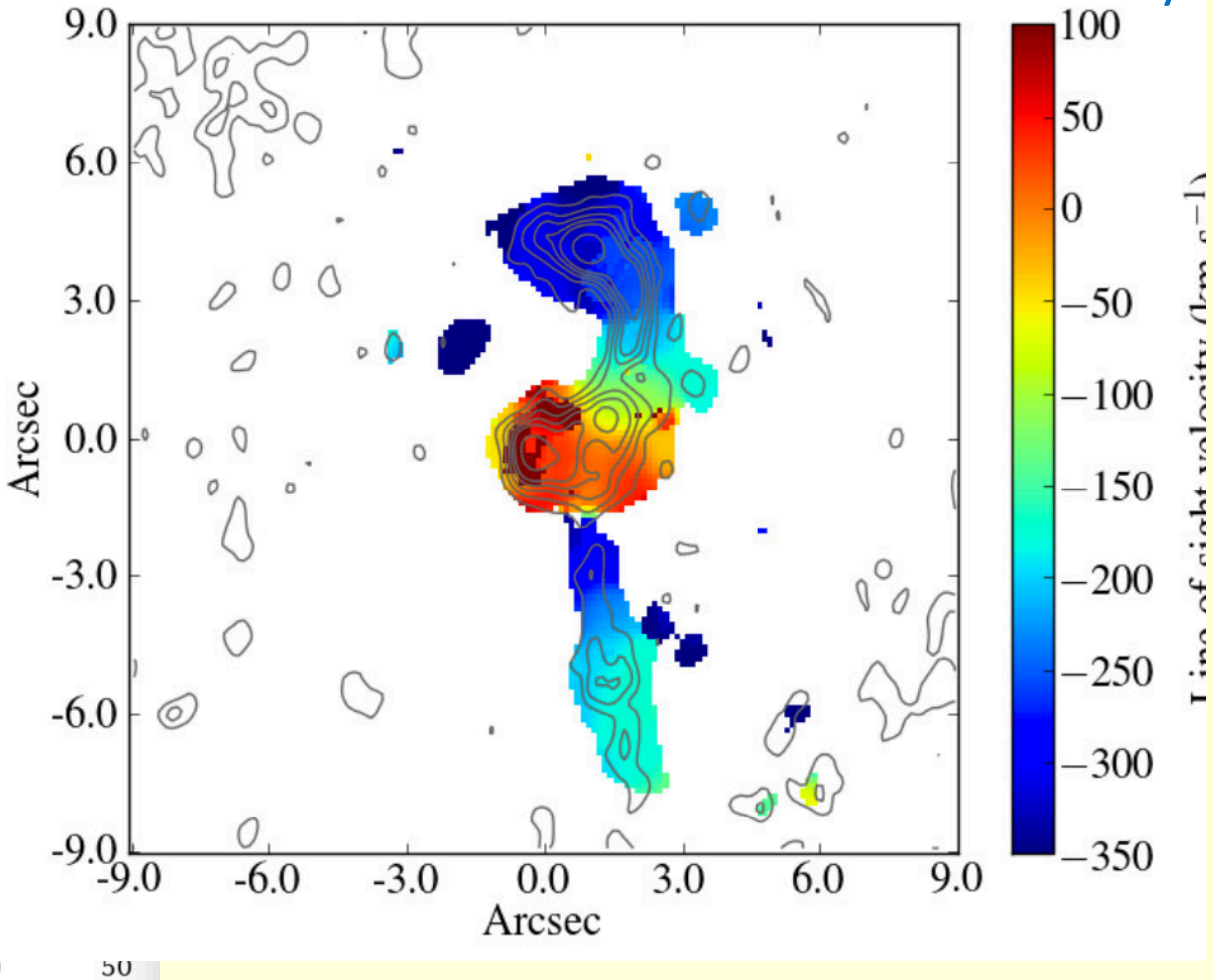
McN+14



Abell 1795 Molecular Gas + Radio Lobes + stars: Uplift?



Radial Velocity



Russell + 17

Struggles to lift, yet most molecular clouds off nucleus

Precipitation models problematic: role of free-fall time unclear, isentropic cores not observed

Conjecture: "stimulated" feedback

McNamara + 16, Hogan 17a,b

$t_c/t_{ff} \leq 1$ *how can classical criterion for thermal instability be satisfied?*

Lift low entropy gas to higher altitude – stimulated feedback

$t_c/t_l \leq 1$ *infall time* at *terminal speed* promotes thermally unstable cooling

Conjecture consistent with ALMA and Chandra data:

-- Uplift (circulation) behind bubbles observed in X-rays and molecular gas

Werner + 11, Simionescu +08, Kirkpatrick + 11, 15

-- Slow molecular gas velocities indicate terminal speed governs thermal instability

McN+16, 14, Russell+16

-- Atmospheres with short cooling times without bubbles lack cold gas

e.g. Abell 2029

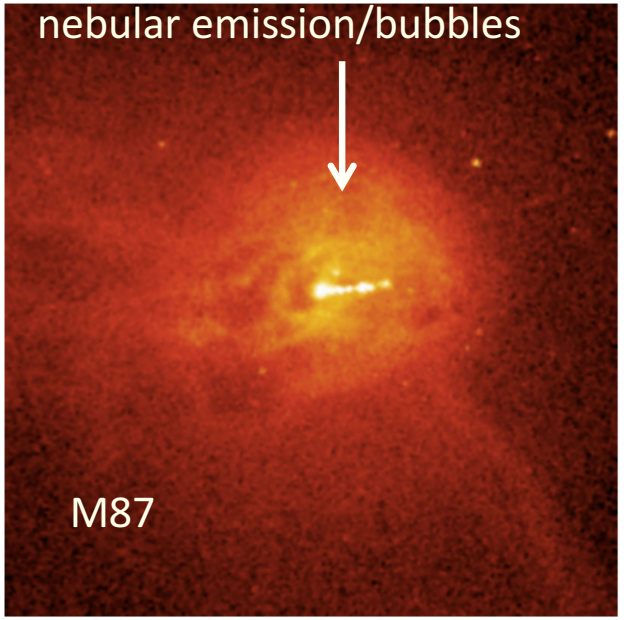
lifting hot gas that cools in bubble wakes is plausible

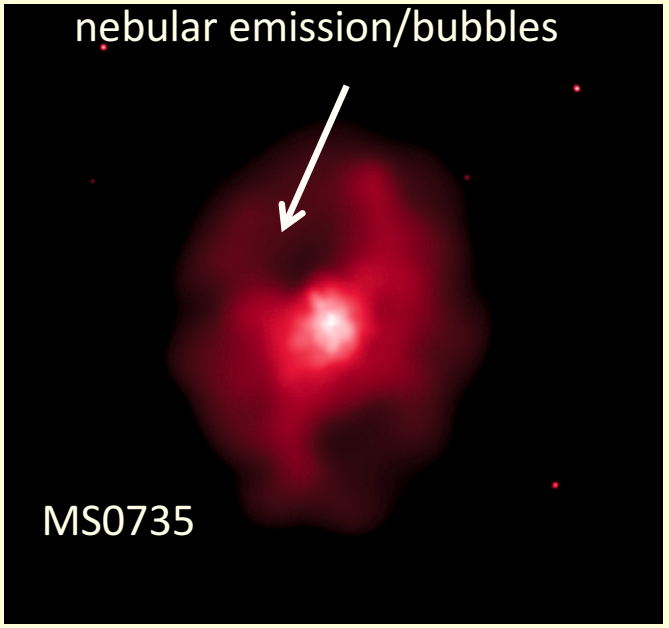
Revaz 08, McNamara + 14, 16

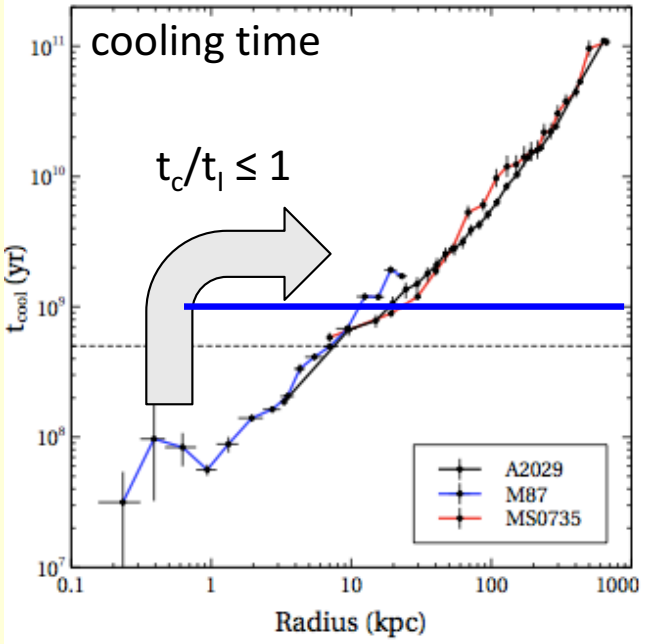
"Stimulated" Feedback: $t_c/t_l < 1$ requires AGN to lift gas

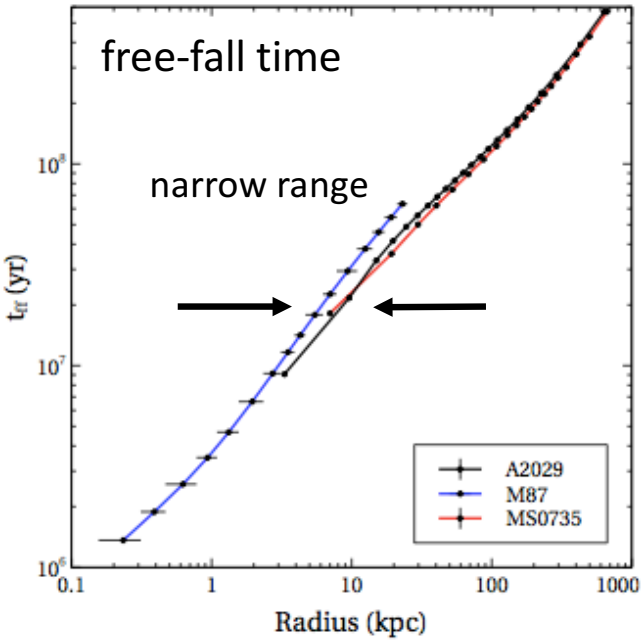
McN + 16

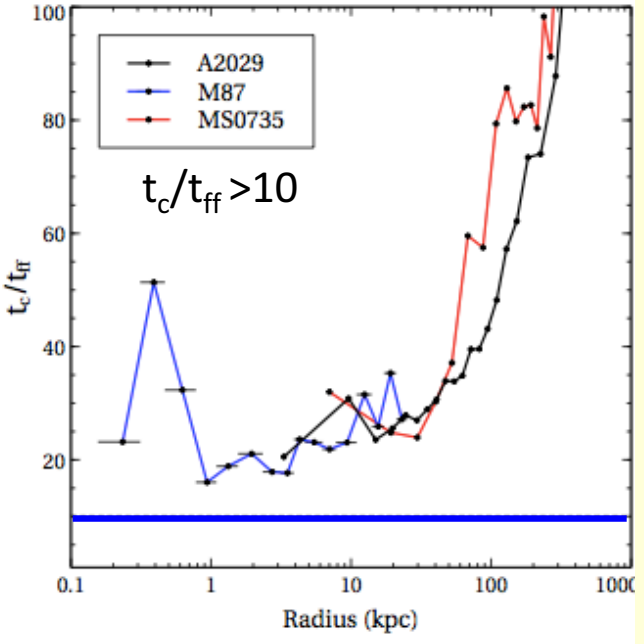
the spoiler



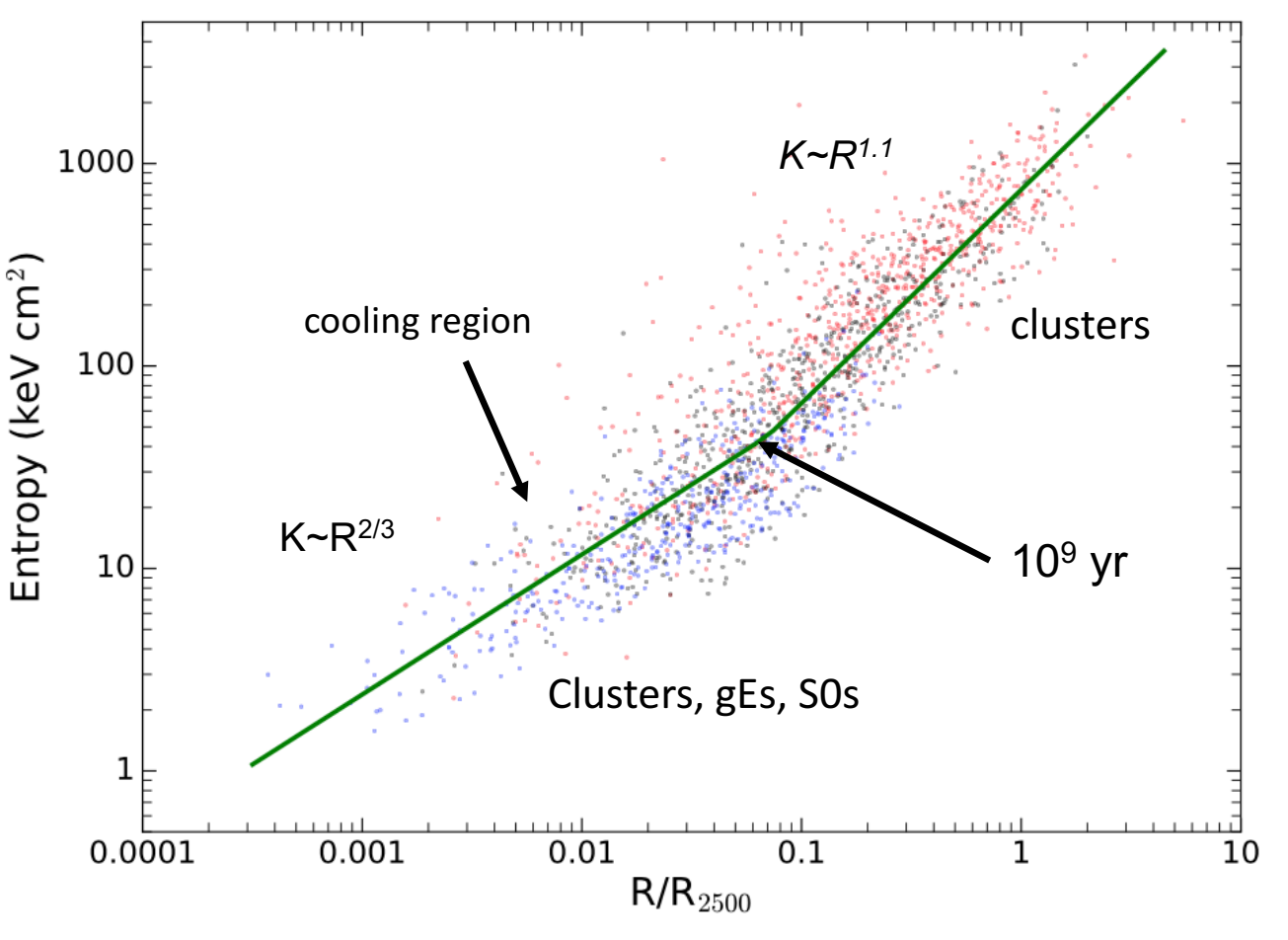








A Universal Entropy Profile for Hot Atmospheres



$K{\sim}R^{1.1}$ $R > 0.1R_{2500}$
$K{\sim}R^{2/3}$ $R < 0.1R_{2500}$

Babyk + 2017, submitted

-- Gentle feedback

-- Thermally unstable cooling in $K{\sim}R^{2/3}$ region

Calibration standard for simulations

Summary

--ALMA & Chandra X-ray images show hot and cold gas lifted behind X-ray cavities

-- Cooling & Feedback stimulated by uplift may solve problems with precipitation model:

1) t_c/t_{ff} never falls below 10
2) ratio insensitive to free-fall time

Stimulated Feedback:

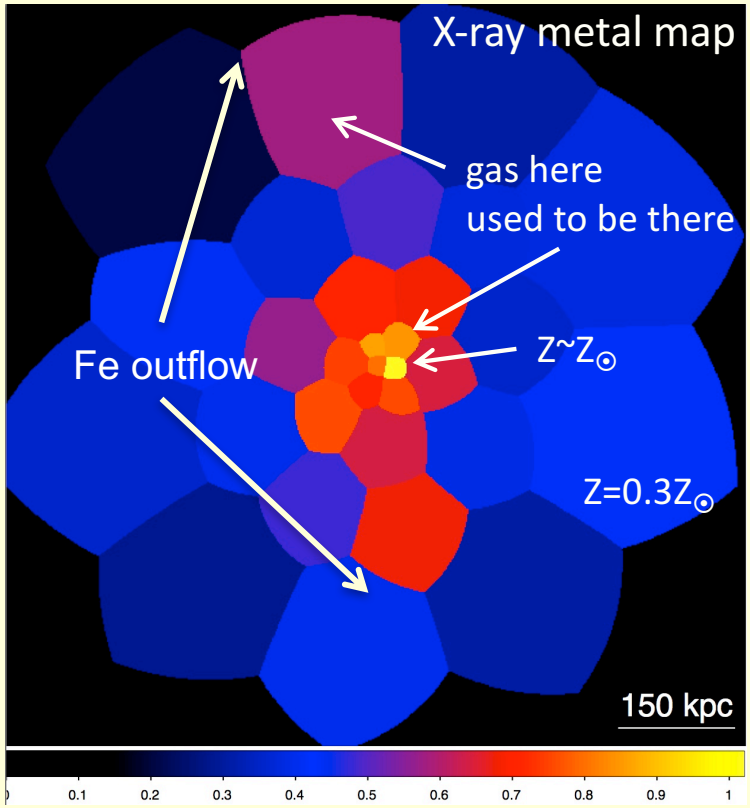
$t_c/t_l < 1$, where t_l is referenced to lifting altitude

t_l bounded by terminal speed and free-fall time

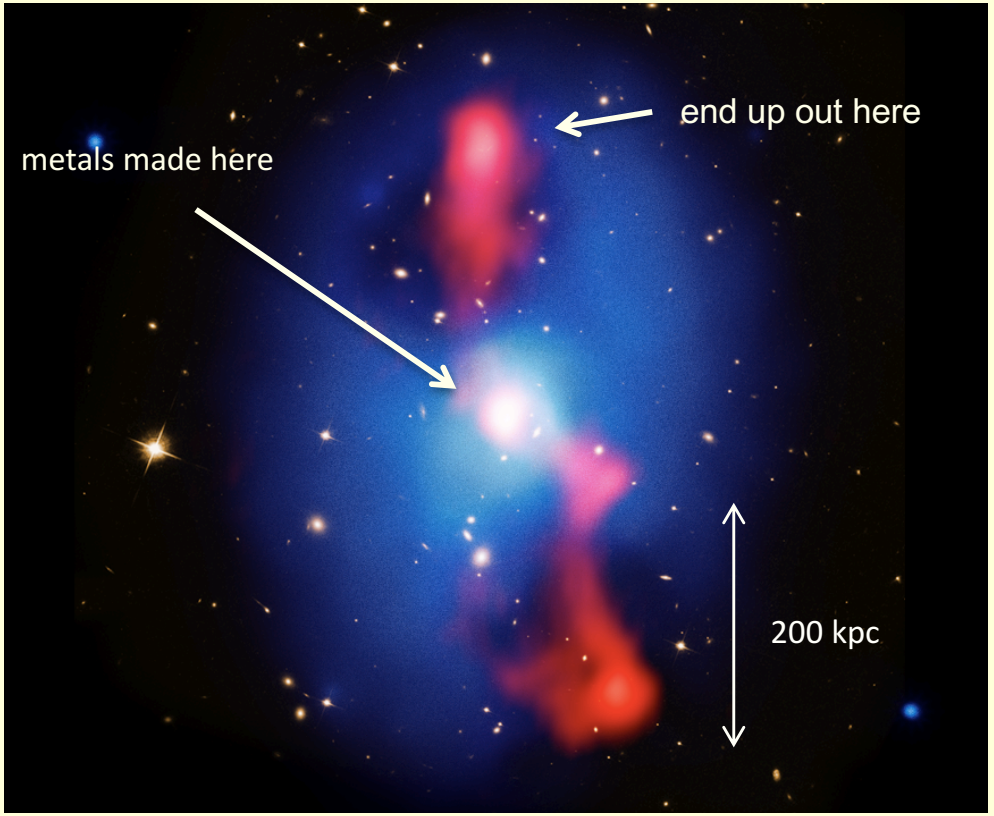
General: any lifting mechanism (merger, sloshing) can stimulate cooling

McNamara+2016, Hogan + 17a,b, Pulido+17

Uplifted Hot Gas traced by metals



R_{Fe}~300 kpc



McN+09, 12
Vantyghem + 14

X-ray, VLA, HST

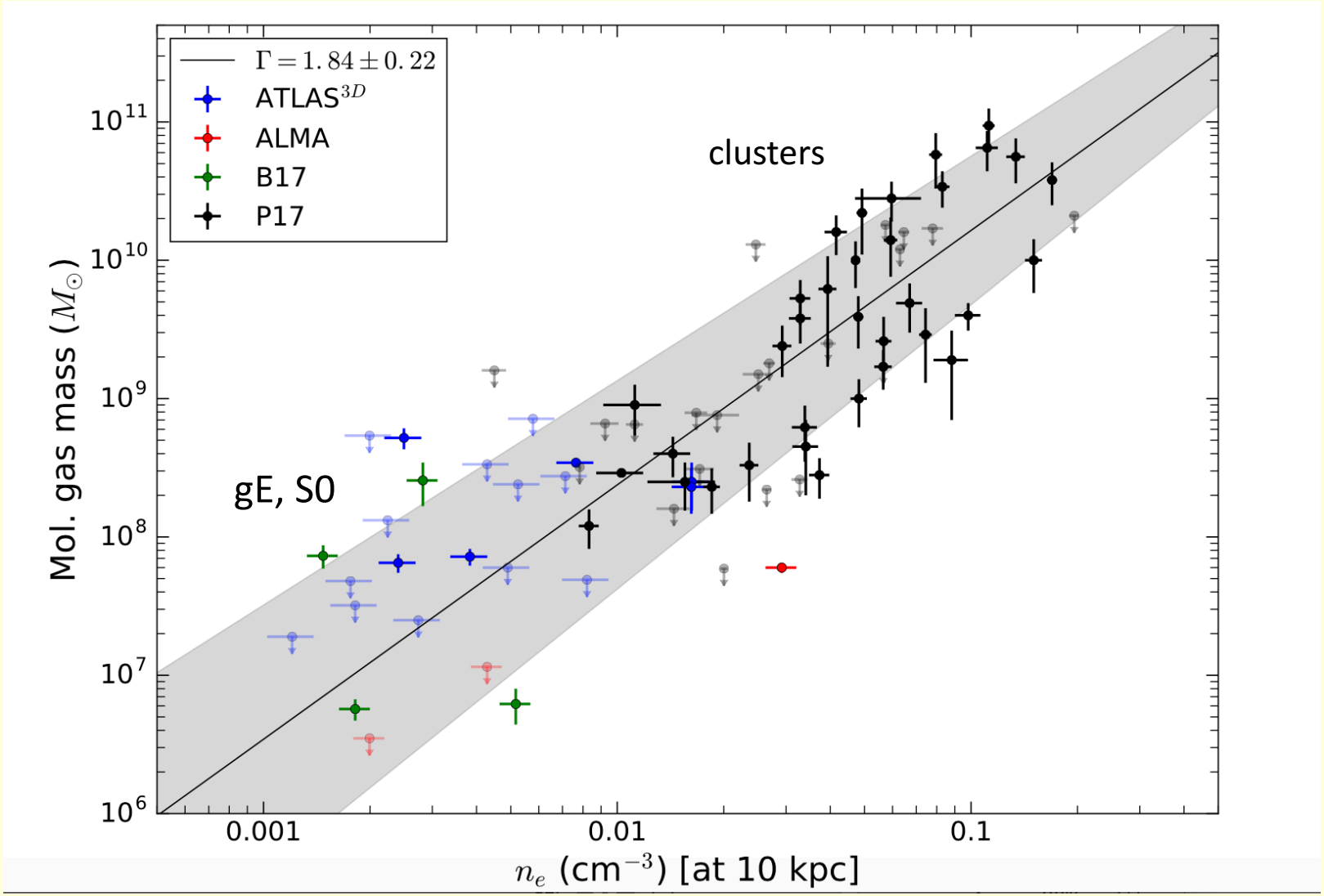
P_{jet}~ 3x10^{46} erg s^{-1}

E_{jet} ~ 10^{62} erg

Lifted/displaced mass ~ 10^{10} $M_{\odot}$

Consistent with Simionescu + 08, Werner +11, Kirkpatrick 09,11,14, Gitti + 11

Molecular gas mass correlates with atmospheric density

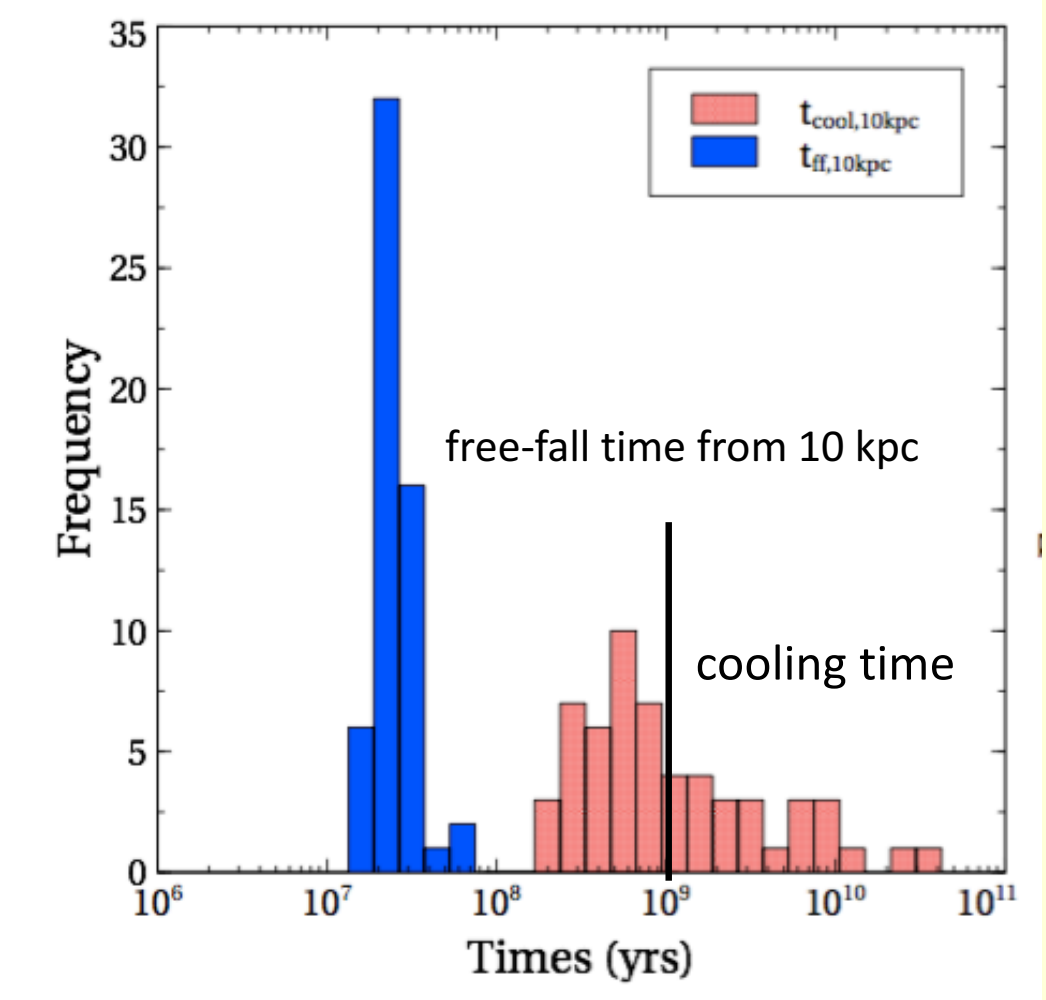


Babyk + in prep

See work by Werner + 14

Pulido + 17

Cooling time drives the ratio



Based on accurate halo mass profiles to within 10 kpc in clusters Hogan +17,a,b
proper accounting for central resolution effects