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- CMB shows remarkable uniformity at epoch of recombination (380,000 yrs)
  - smallest halos collapse first
  - massive clusters grow by accretion and mergers

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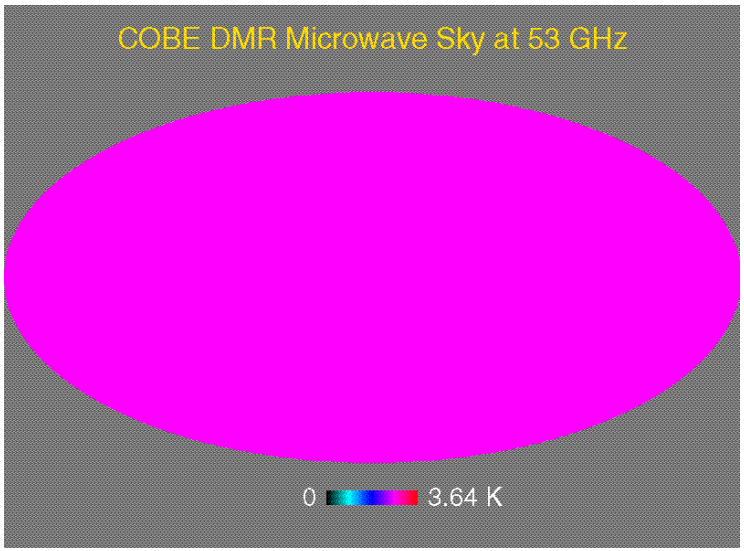

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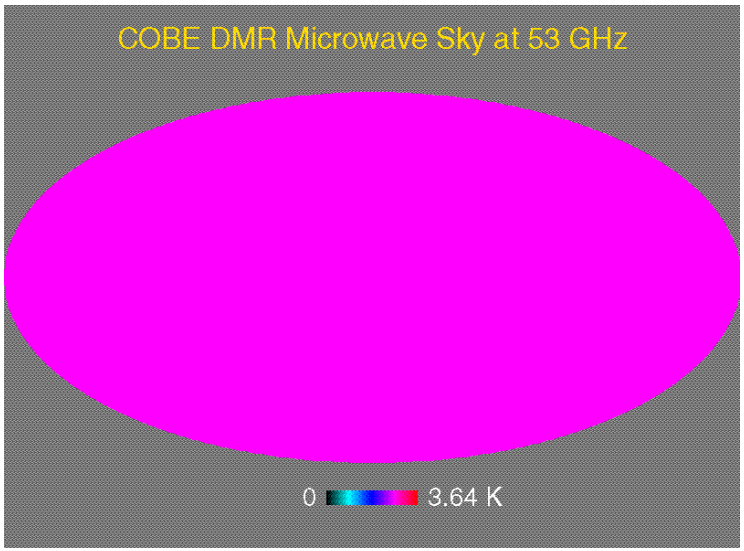

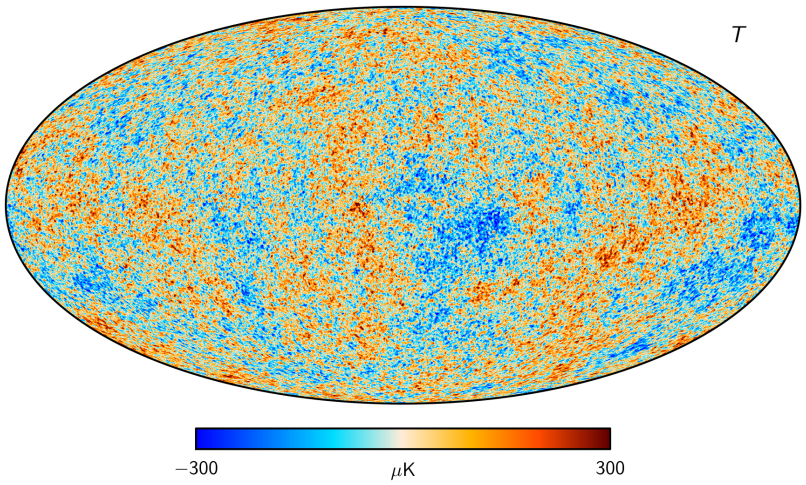

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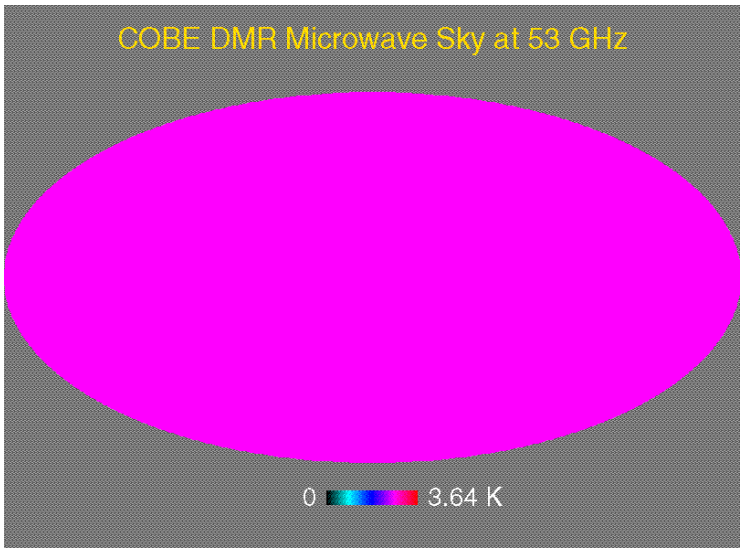

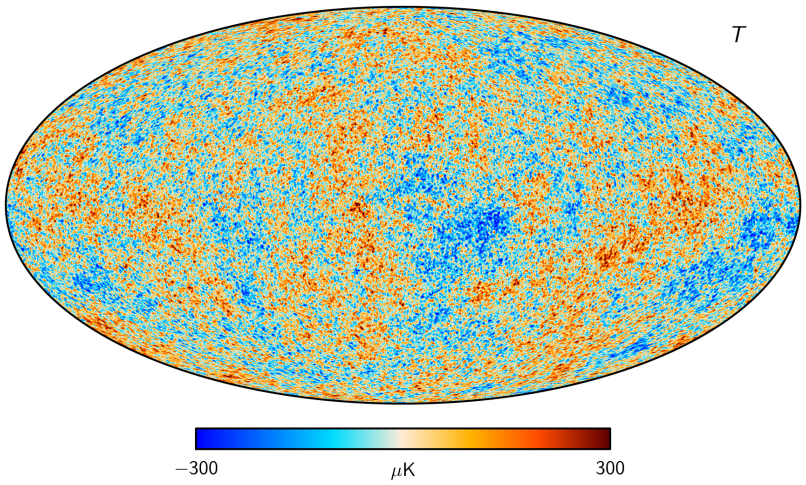

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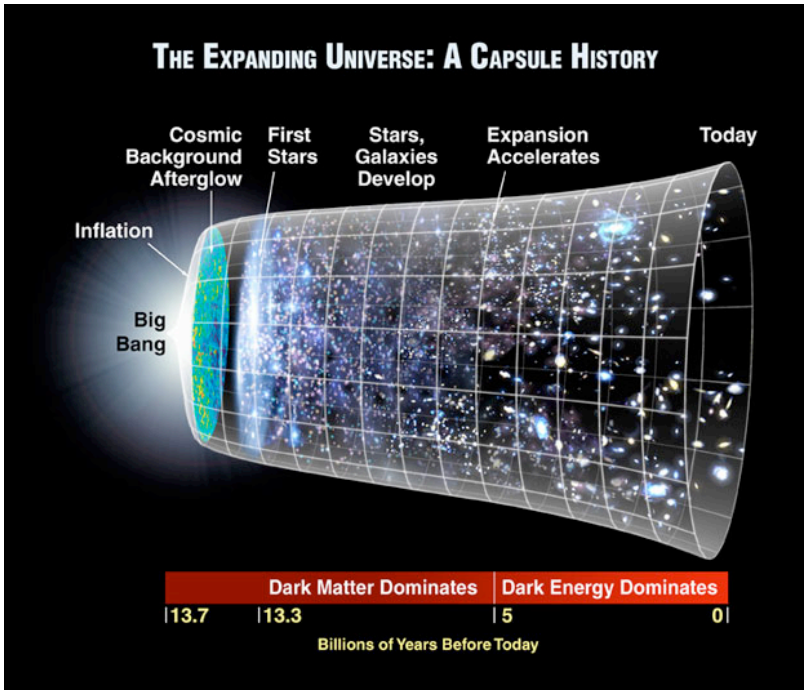

Cooling Flows

Allen/Fabian

- **Strong surface brightness peak --> dense gas --> short cooling time**
- Hot gas radiates – gas must cool unless reheated
- **Mass Deposition rates are calculated to be large (100 -1000 M/yr) - more than 50% of clusters**
- But large amounts of cool gas were never detected

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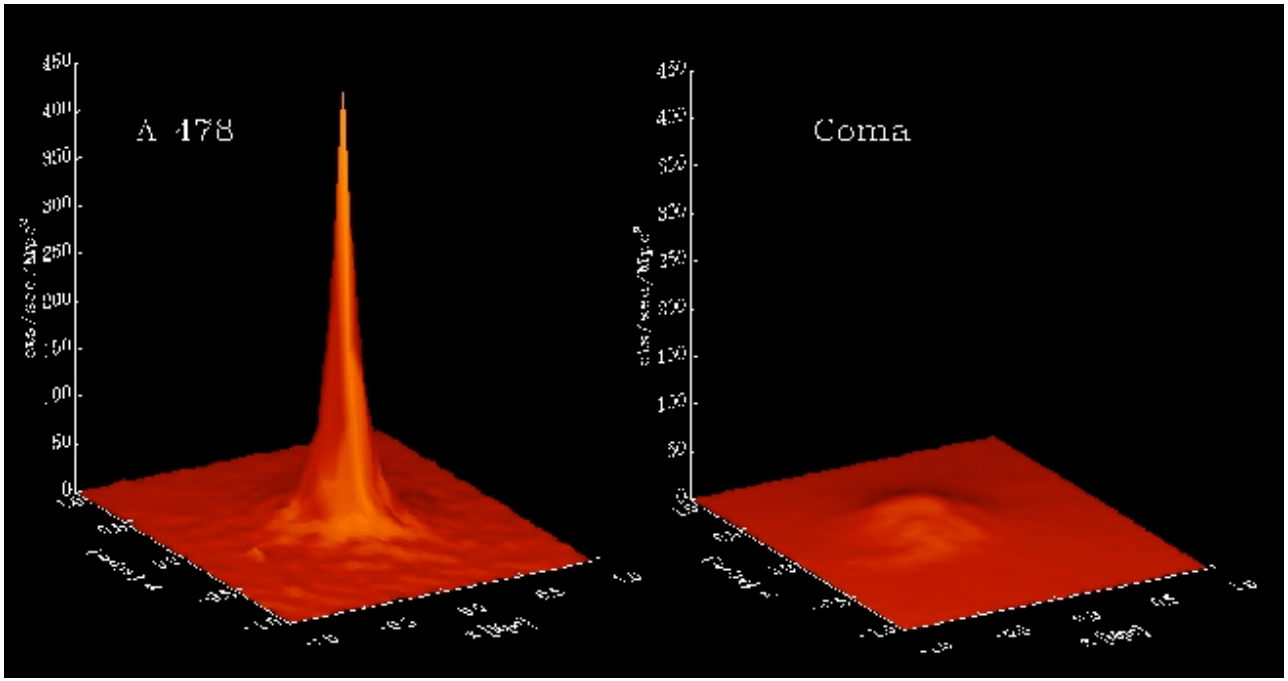

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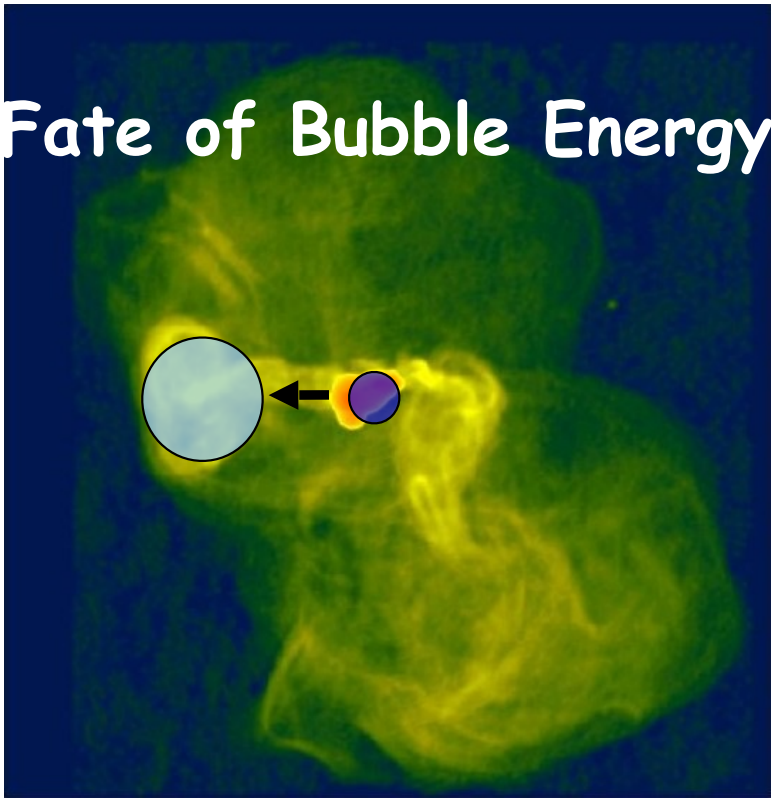


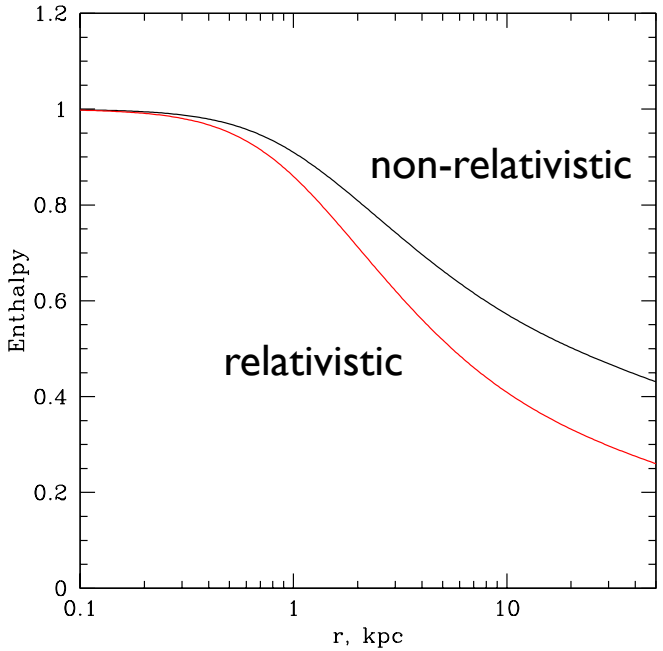
Rising bubble loses energy to surrounding gas

$$f = (p_1 / p_0)^{(\gamma-1)/\gamma}$$

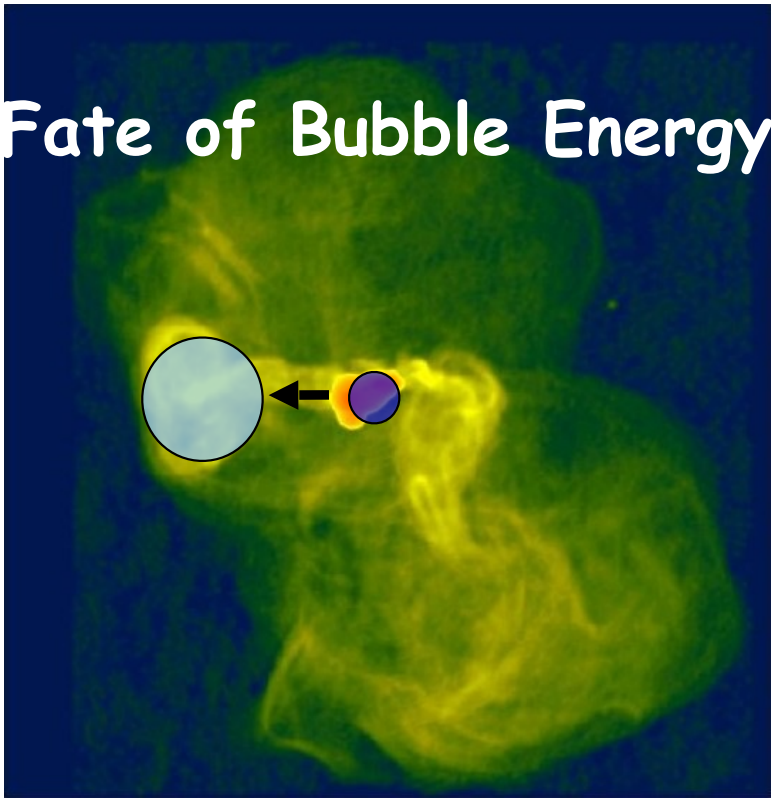
Generates gas motions in wake

Kinetic energy (eventually) converted to thermal energy (via turbulence)

Bubble energy remaining vs. radius



$$\Delta E_{gas} = -\Delta E_{Bubble} = -\Delta \frac{\gamma}{\gamma - 1} PV = E_0 \left[1 - \left(\frac{P}{P_0} \right)^{1-1/\gamma} \right]$$



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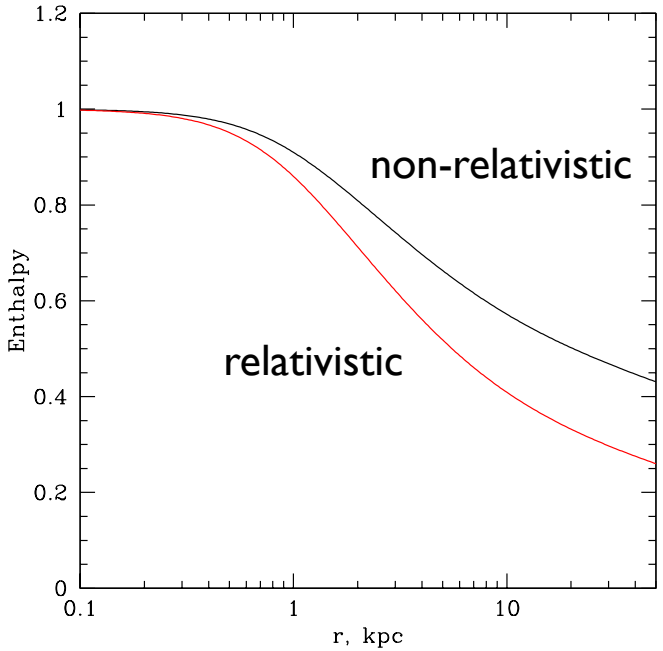

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Feedback (black holes + hot gas) and Baseball

Early type (bulge) galaxies (and massive spirals - see Akos Bogdan's papers)
- like a baseball team

Batter = SMBH - sometimes hits the ball (outbursts)
infrequent
exact trigger unknown
different sizes (walks, singles, … home runs)

Pitcher = provides ball/fuel (cooling gas for accretion)

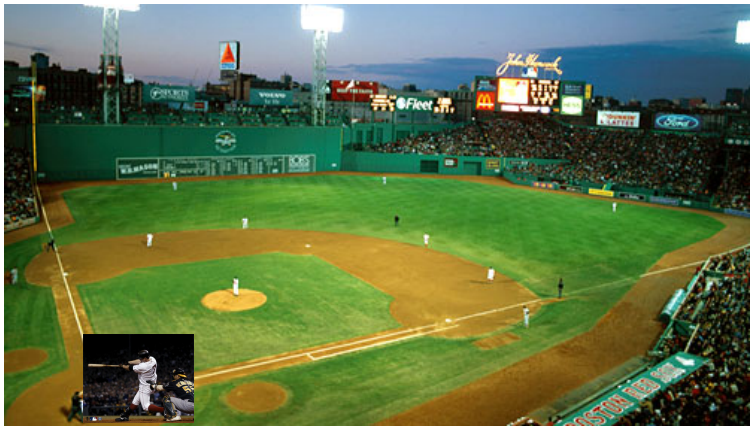
Hot X-ray emitting gas = fielders
capture AGN output

Fielders are critical

No fielders (no gas)

==> No energy capture

No feedback



Unifies SMBH, AGN activity,
Galaxy properties (red/blue)
X-ray "cooling" flows

Gas Provides archive of AGN activity