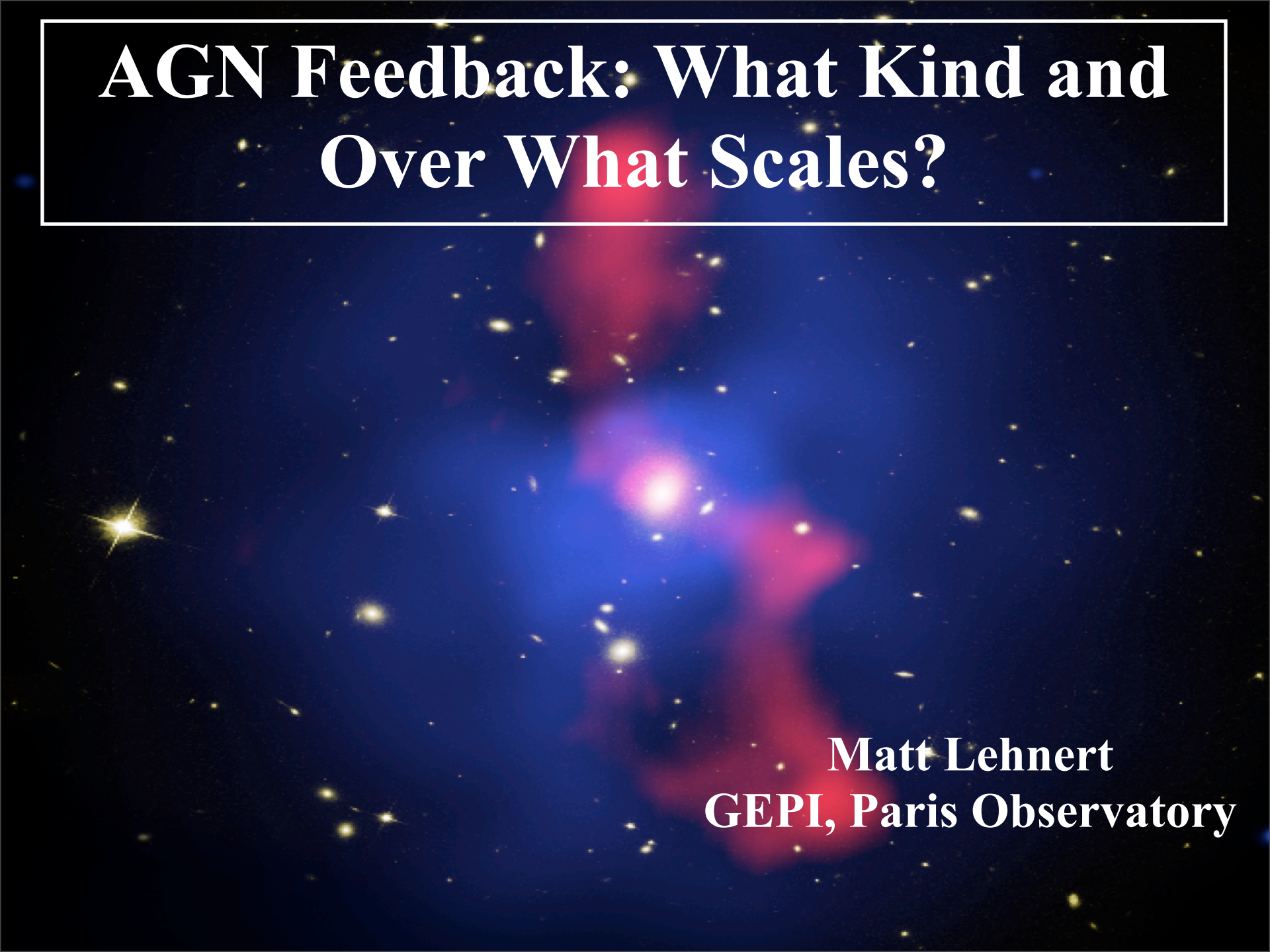
AGN Feedback: What Kind and Over What Scales?



Matt Lehnert
GEPI, Paris Observatory

Coordination with Theory(ist)

" … show that AGN can drive winds …"

Volker Springel

OK!

Feedback: Over What Scale?

10^{-1-1} pc

10^{1-3} pc

10^{3-4} pc

[M/H] and $\vec{B}$

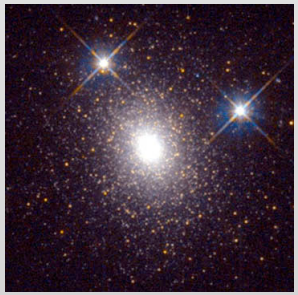
Self-reg & Eddington limiting

M_{BH}-σ & mass disposal

10^{4-6} pc

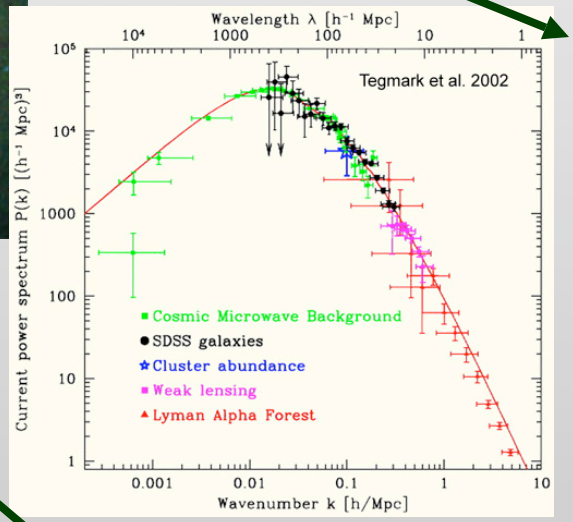
Regulate ISM Galaxy formation

10^{6-8} pc



Dynamical evolution of galaxy centers & star-clusters

Heat halo & cluster gas



LSS

AGN Feedback: Lessons from Superwinds

Have enough power

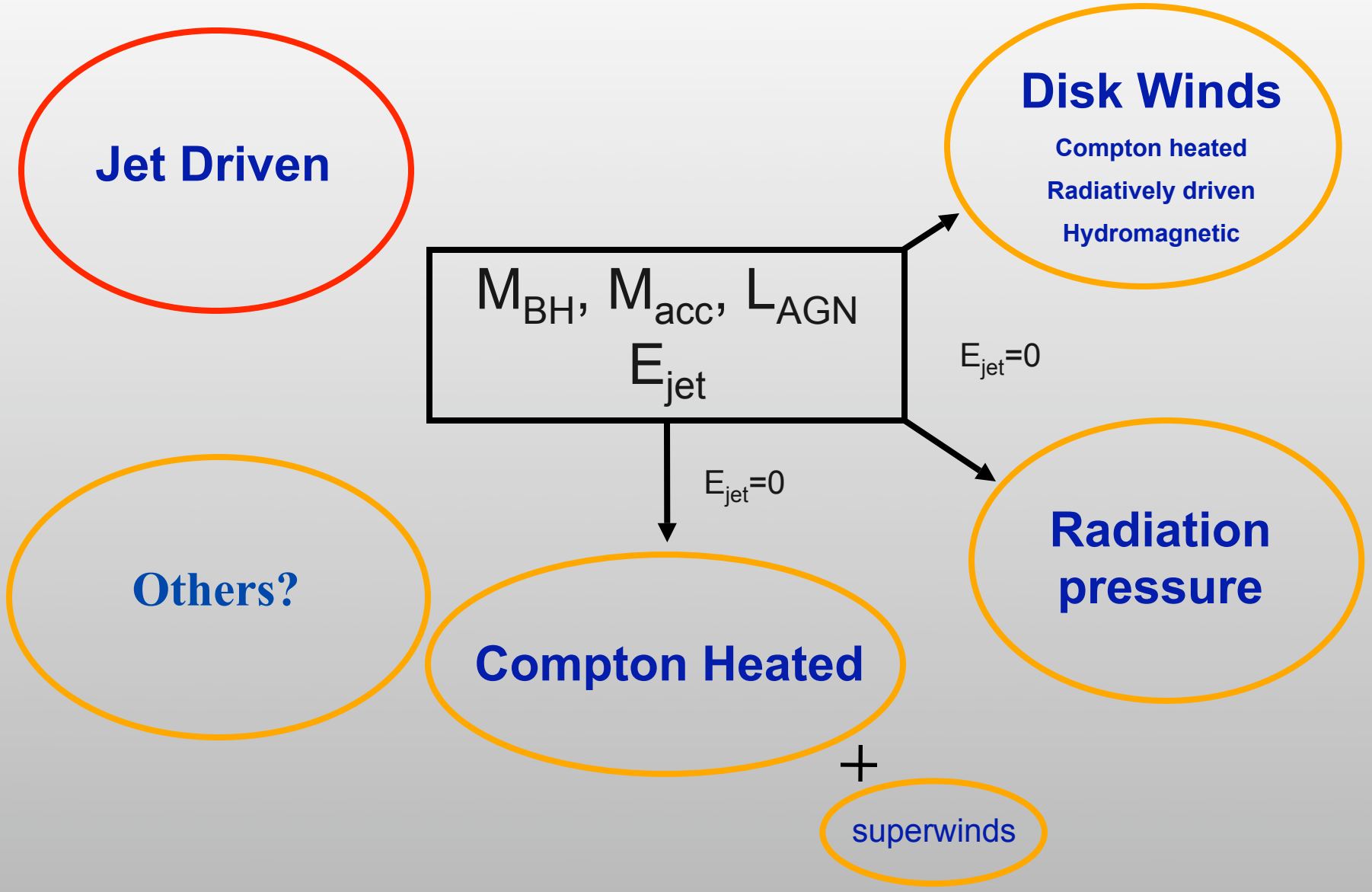
"Feedback" will be a multi-wavelength phenomenon

Need diagnostics of both heating and cooling

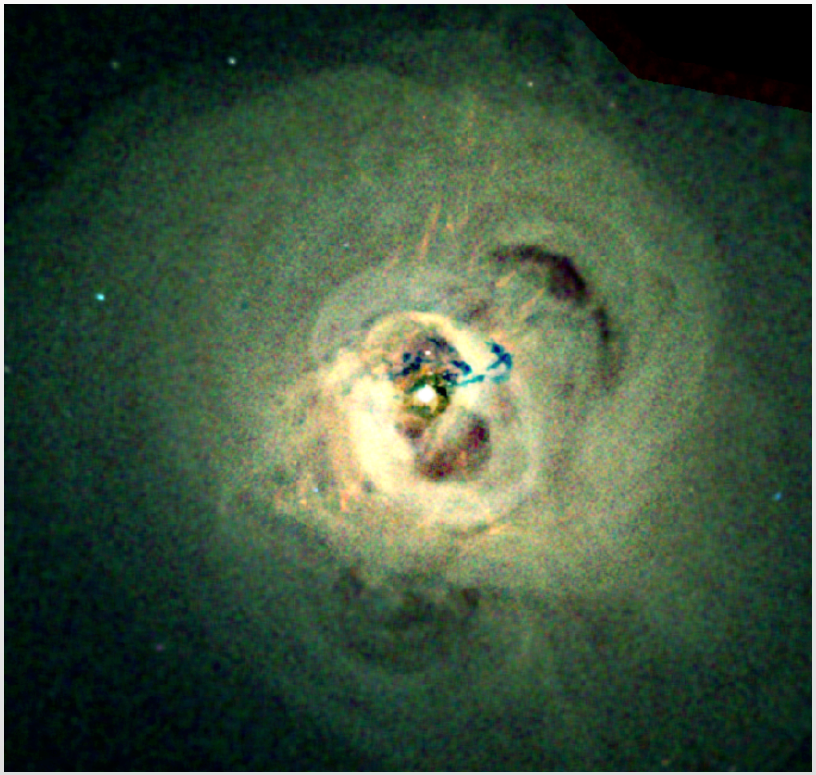
Dichotomy of nature – radio loud vs. radio quiet, etc.

Are there several mechanisms?
There are no golden observations!

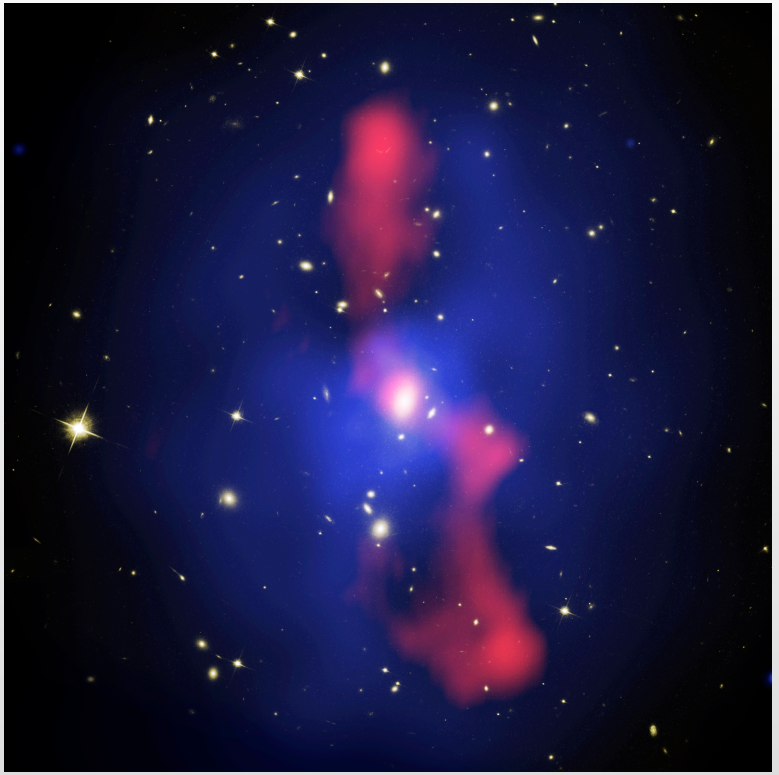
From Inputs to Outputs



At Cluster Scales



Fabian et al. (2006)

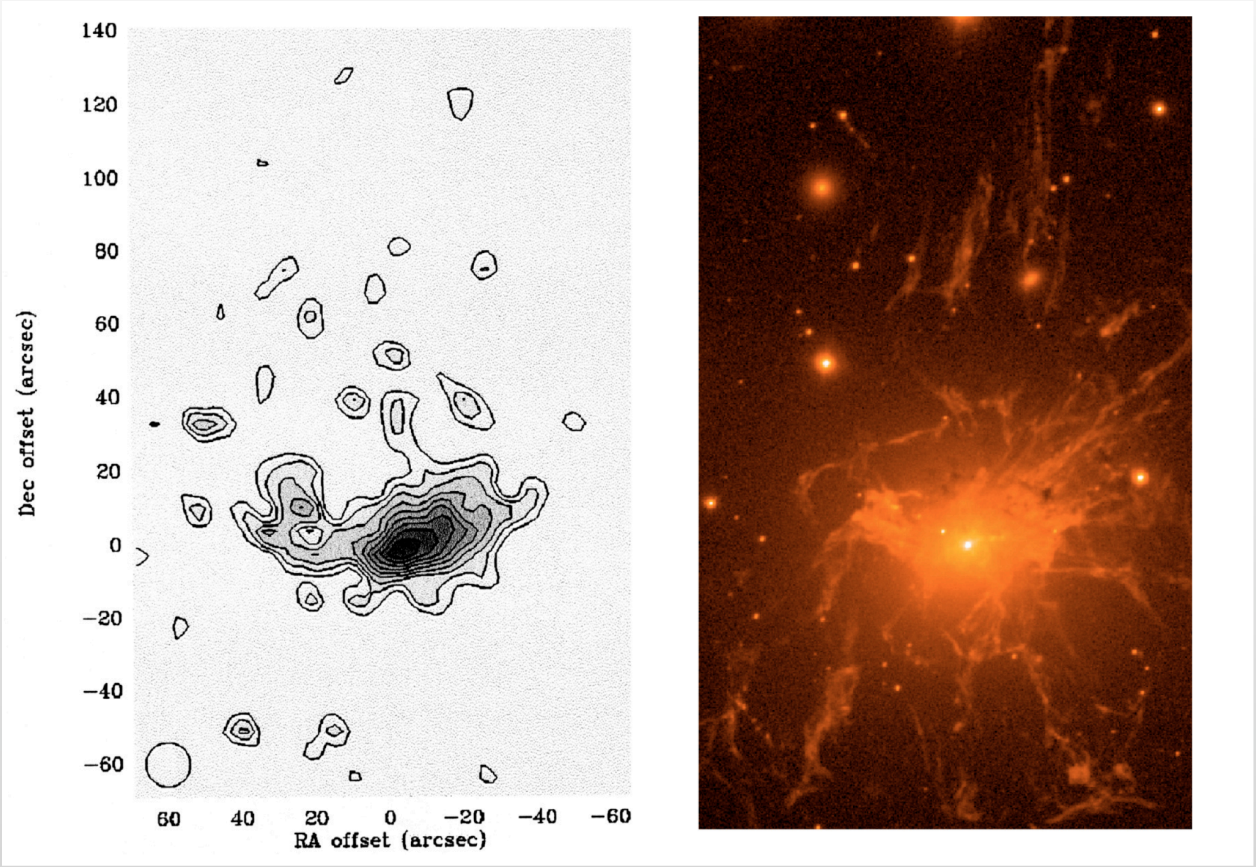


McNamara et al. (2005)

… radio inflates bubbles at low mach numbers which then rise bouyantly … heat the ICM

Cavities are multi-wavelength phenomenon

mm and strong optical line emission …



M_{H_2}~2-5 x 10^{10} $M_\odot$

Nice correlation between line emission and molecular mass.

Perseus core; Salomé et al. (2006)

… because of complexity– only recently have we obtained any deep understanding …

Cavities are multi-wavelength phenomenon

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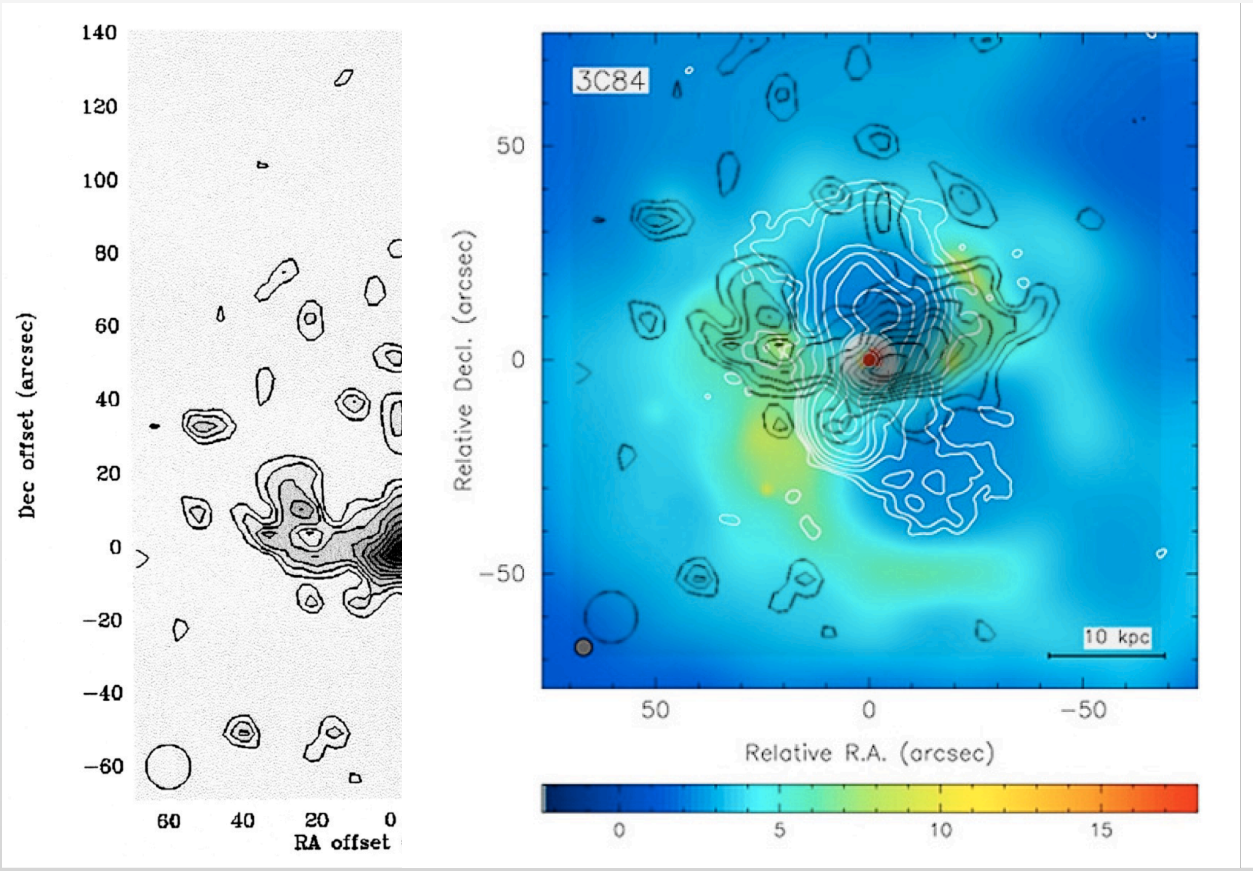

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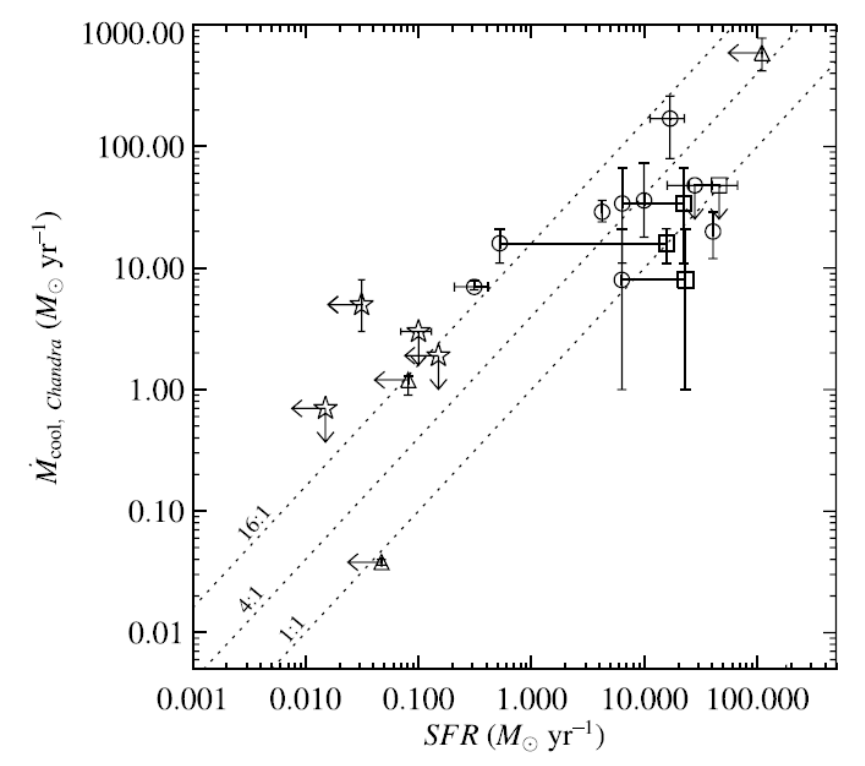
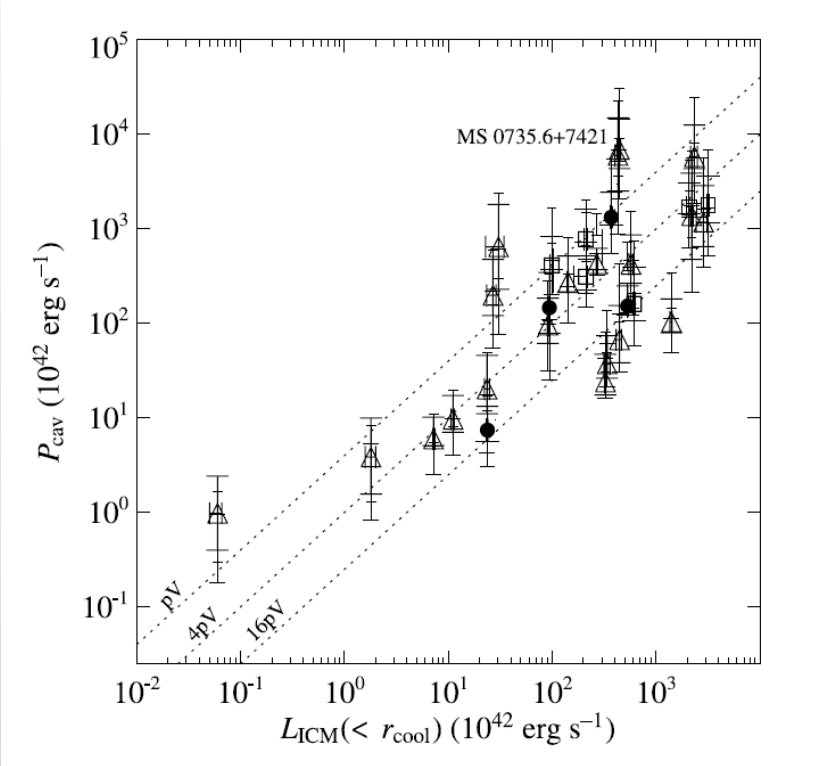
Radio Galaxies and ICM

Heating prevents star-formation and cooling …





Rafferty et al. (2006)

… what does this imply about smaller scale heating?

The Dual Roles of Radio Sources

Maintenance …

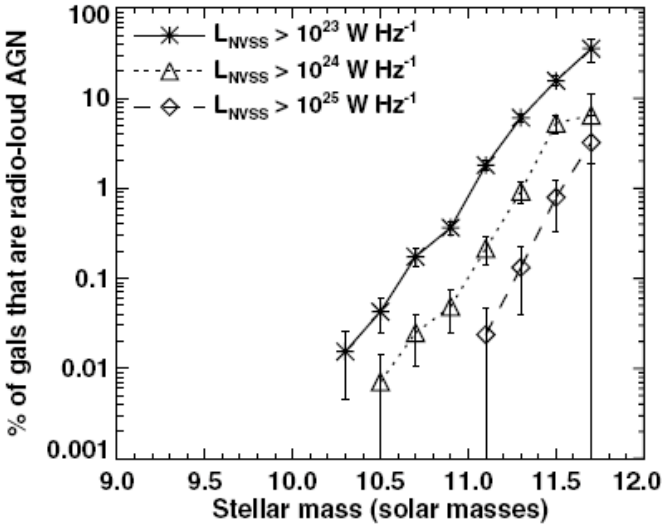
and

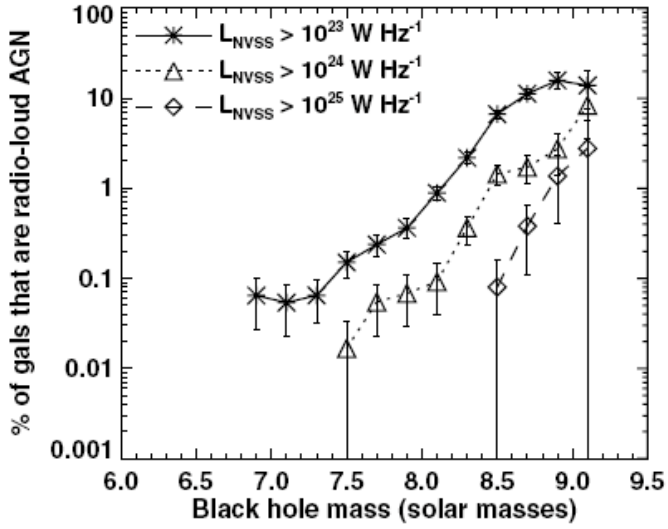
Exorcisms ...

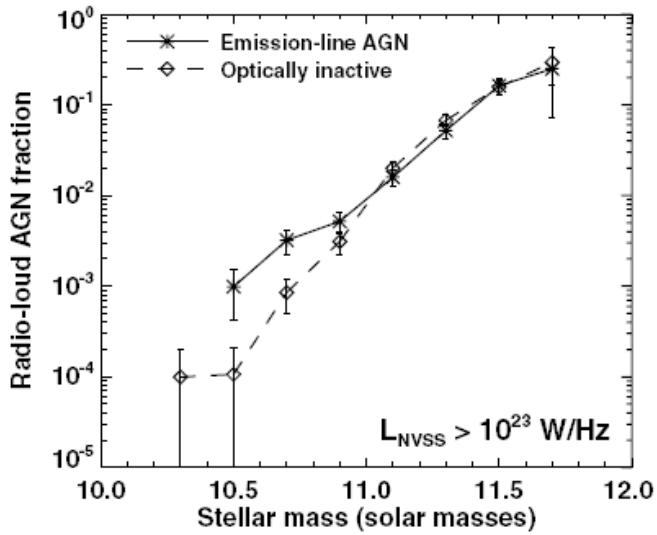
… keeping gas from collapse …removing the ISM …

… from low-z to … high-z

The Importance of Being Radio Loud



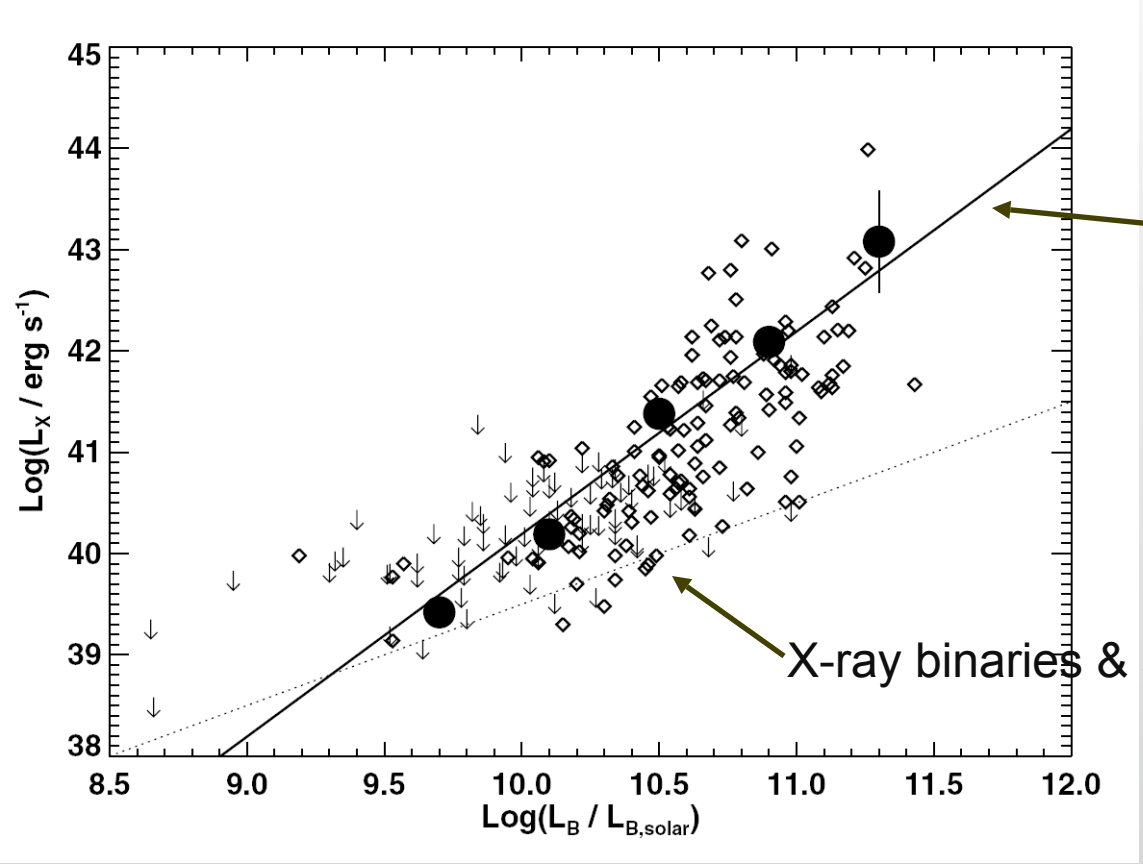




Radio loud sources become important at masses where theoretically expect cooling in the halo to be important.

Best et al. (2005)

Detailed Balance: Influencing Halo

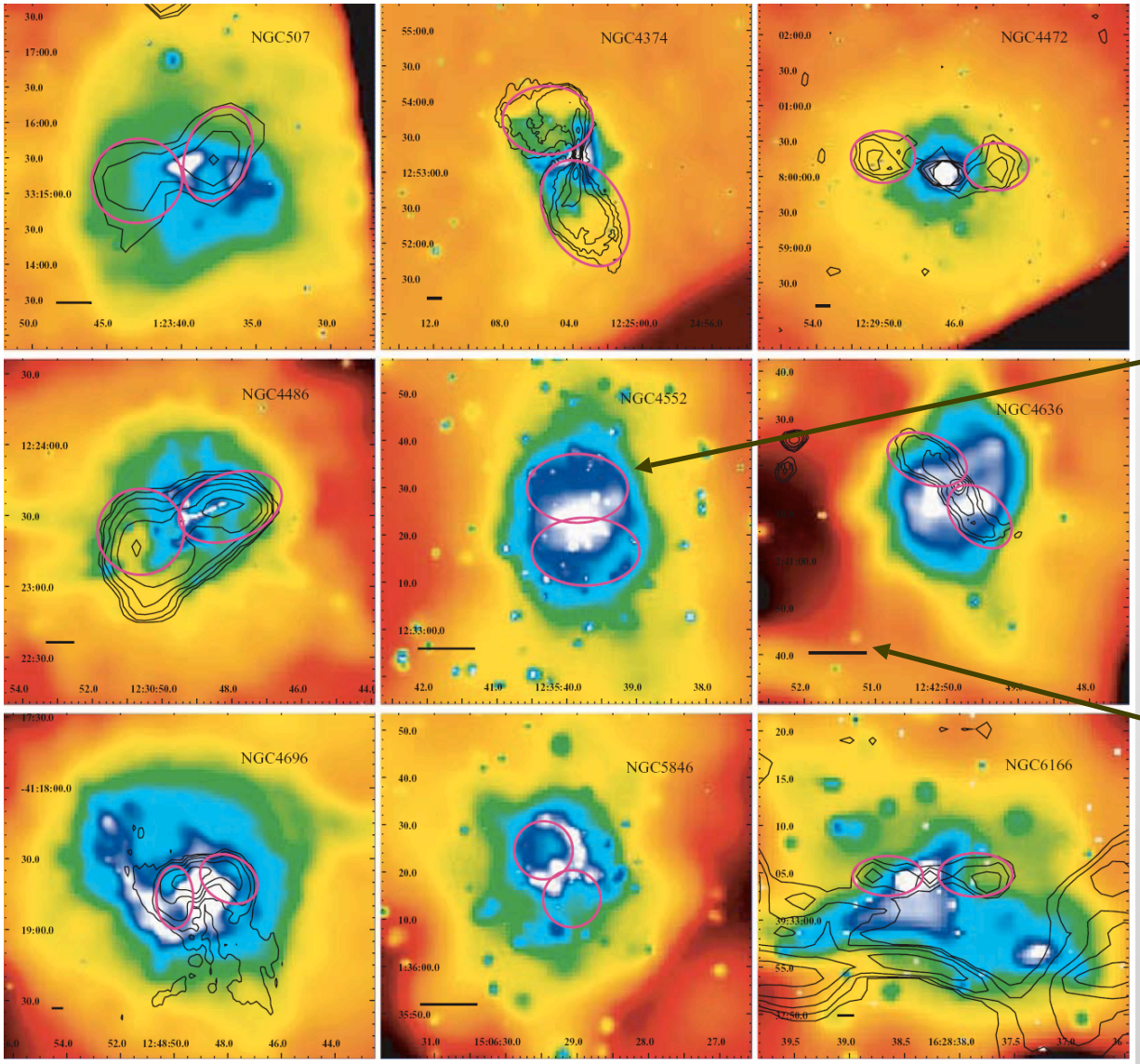


Radio heating = X-ray cooling

X-ray binaries & stars

Best et al. 2005

Detailed Balance: Influencing Halo



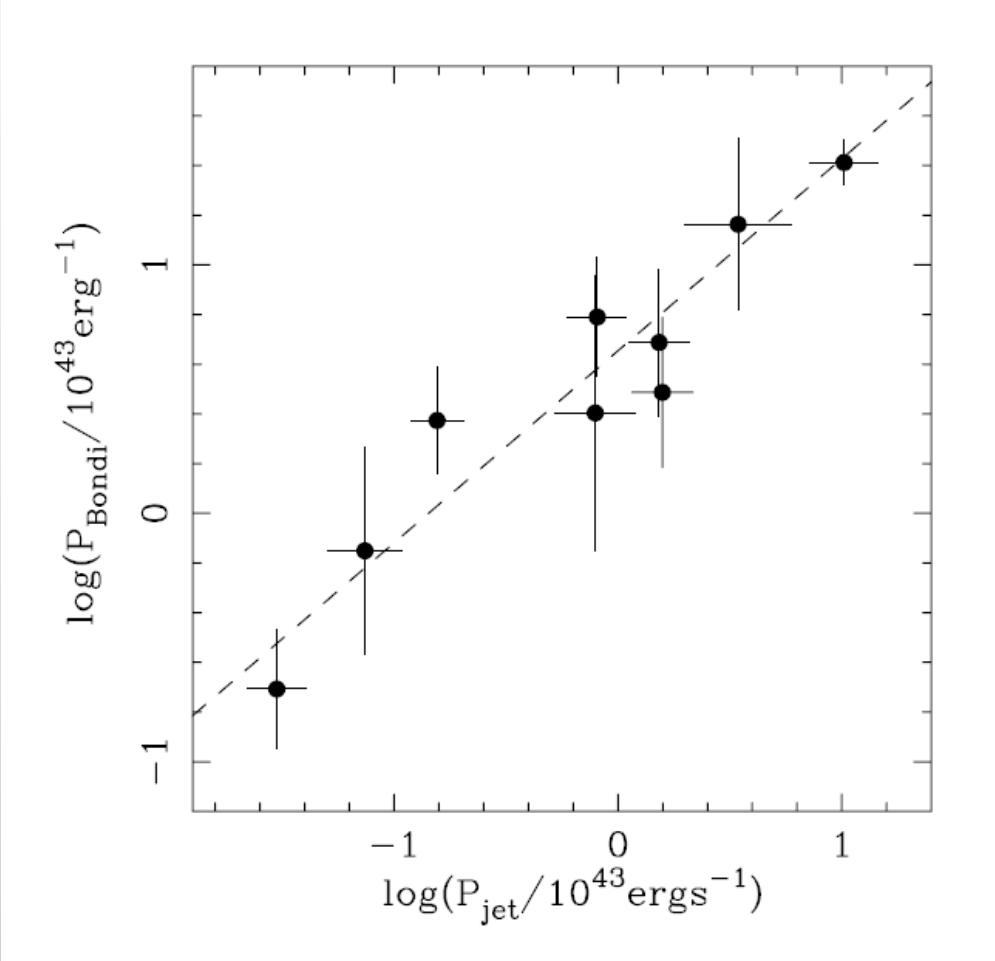
Radio cavities on small scale

1 kpc

Allen et al. 2006

Detailed Balance: Influencing Halo

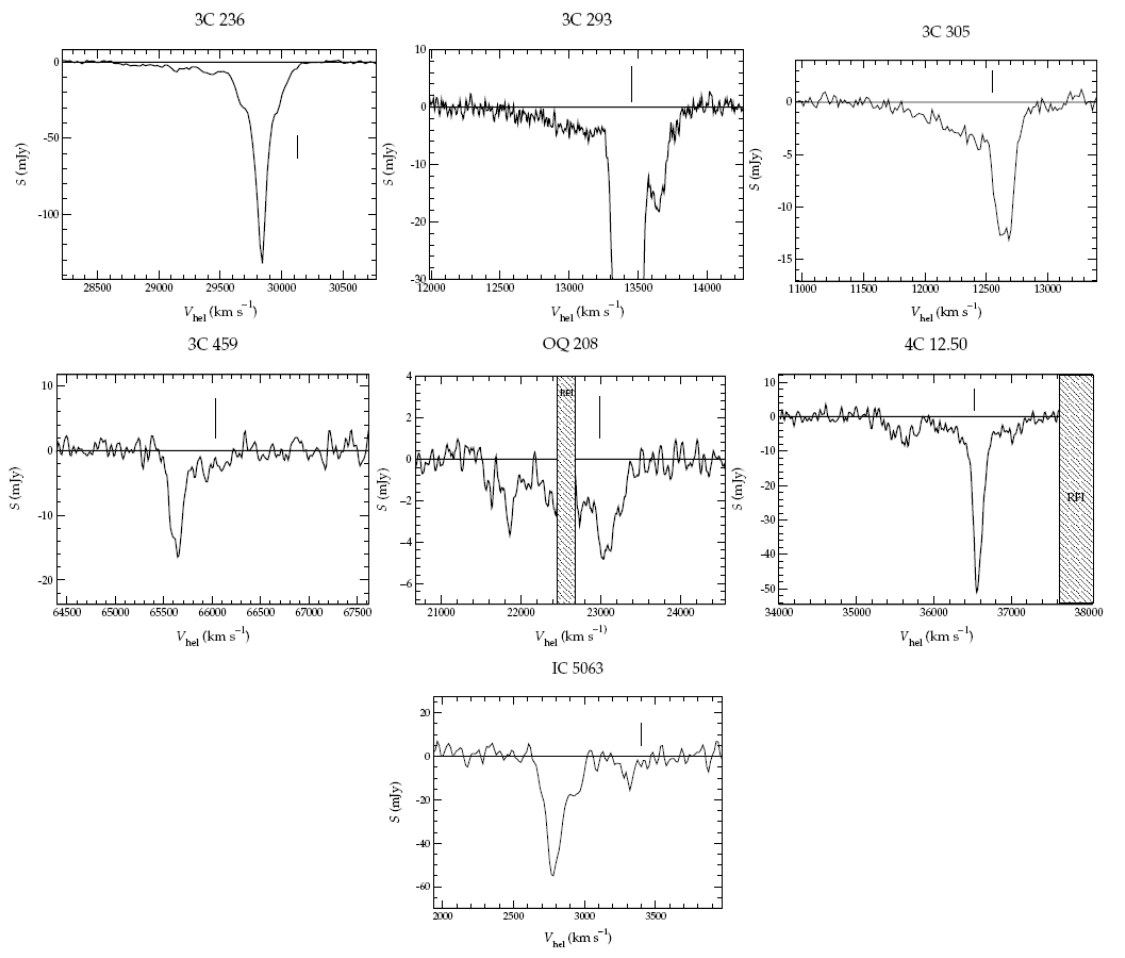
Jet power appears to be related to the accretion energy … challenging to make these estimates however …



Allen et al. 2006

Neutral Outflows

HI observations of nearby by radio loud AGN …another phase!



~1000 km s^{-1}
~1-50 $M_\odot$ yr^{-1}

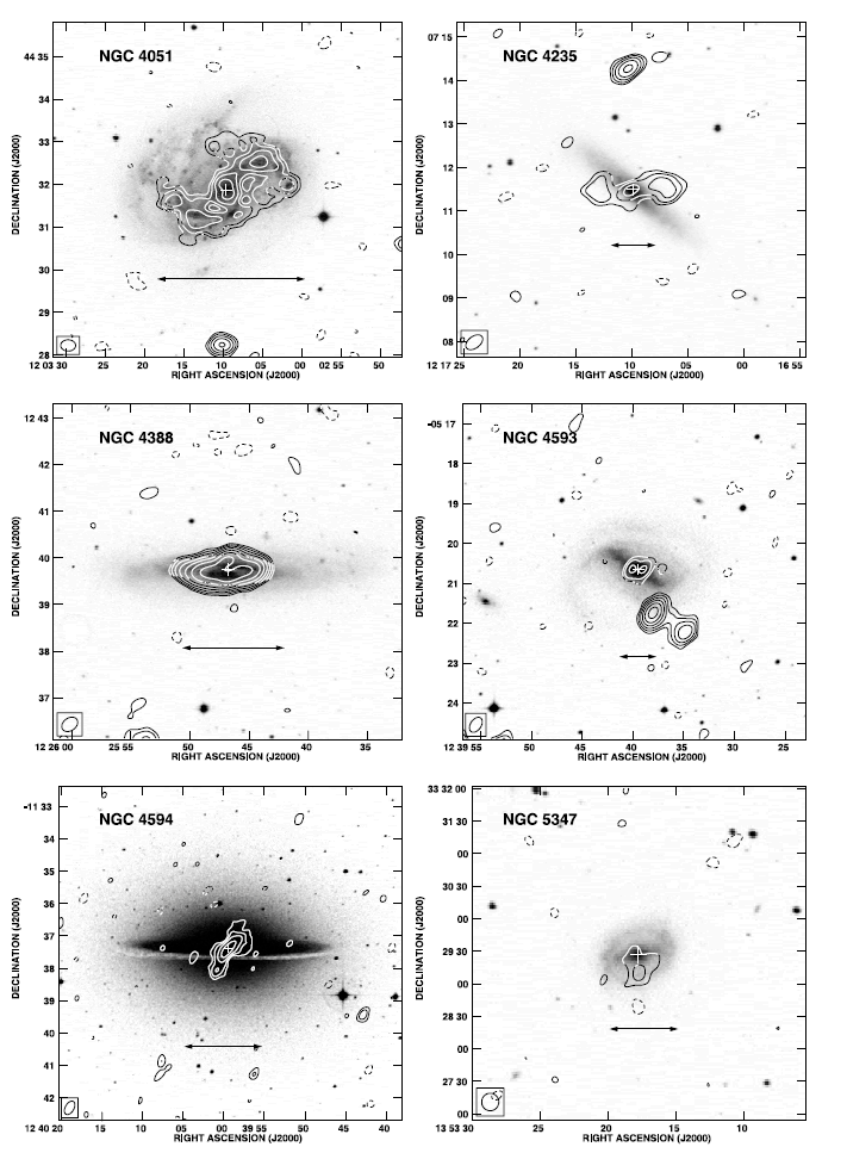
Bulk kinetic energies:
$10^{56\text{-}58}$ ergs

Not enough to excise lots of gas, but good for maintenance.

Morganti et al. 2005

Small Scale Maintanence

Even radio jets (~50%) in nearby Seyferts … on kpc scales



These kpc scale jets:

10^{57} ergs of bulk kinetic energy

These jets decelerate and appear frustrated.

They deposit their energy on bulge scales.

maintenance in bulge

Gallimore et al. 2006

The Duel Roles of Radio Sources

Maintenance …

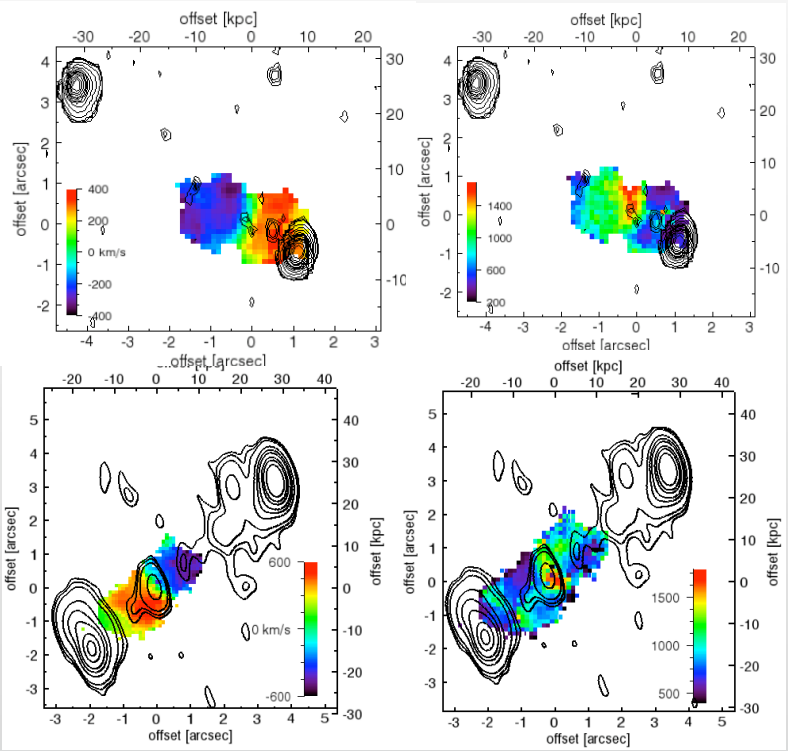
and

Exorcisms ...

… now briefly on exorcisms at high redshift … push gas out in short time scales …

Exorcisms at high redshift

Powerful radio galaxies at high-z are driving incredible outflows …



$10^{60\text{-}61}$ ergs of bulk kinetic energy

Outflow rates of 100-1000 $M_\odot$ yr^{-1}

$L_{mech} \sim L_{bol}$ and efficient coupling

Unbind large masses of gas

Nesvadba et al. 2006, 2007

Summary of Jet Driven "winds"

dM/dt ~1-1000 $M_\odot$ yr^{-1} -- remove ISM or halo

$V_{outflow}$ ~100-5000 km s^{-1}

Couples well with the ISM/IGM – unclear how and why? Lots of entrainment

$E_{kinetic}$ ~$10^{42\text{-}46}$ ergs s^{-1} or ~ L_{bol}

E_{total} ~$10^{56\text{-}61}$ ergs -- enough to heat the circum-nuclear gas, ISM, and ICM

!

This impact is seen at almost every wavelength, in source characteristics, and over a wide range of scales.

Questions about Jet-Driven Winds

"Coordination problem": Powerful radio sources are often in the throes of gas rich mergers. Does the AGN heat everthing? What's left?

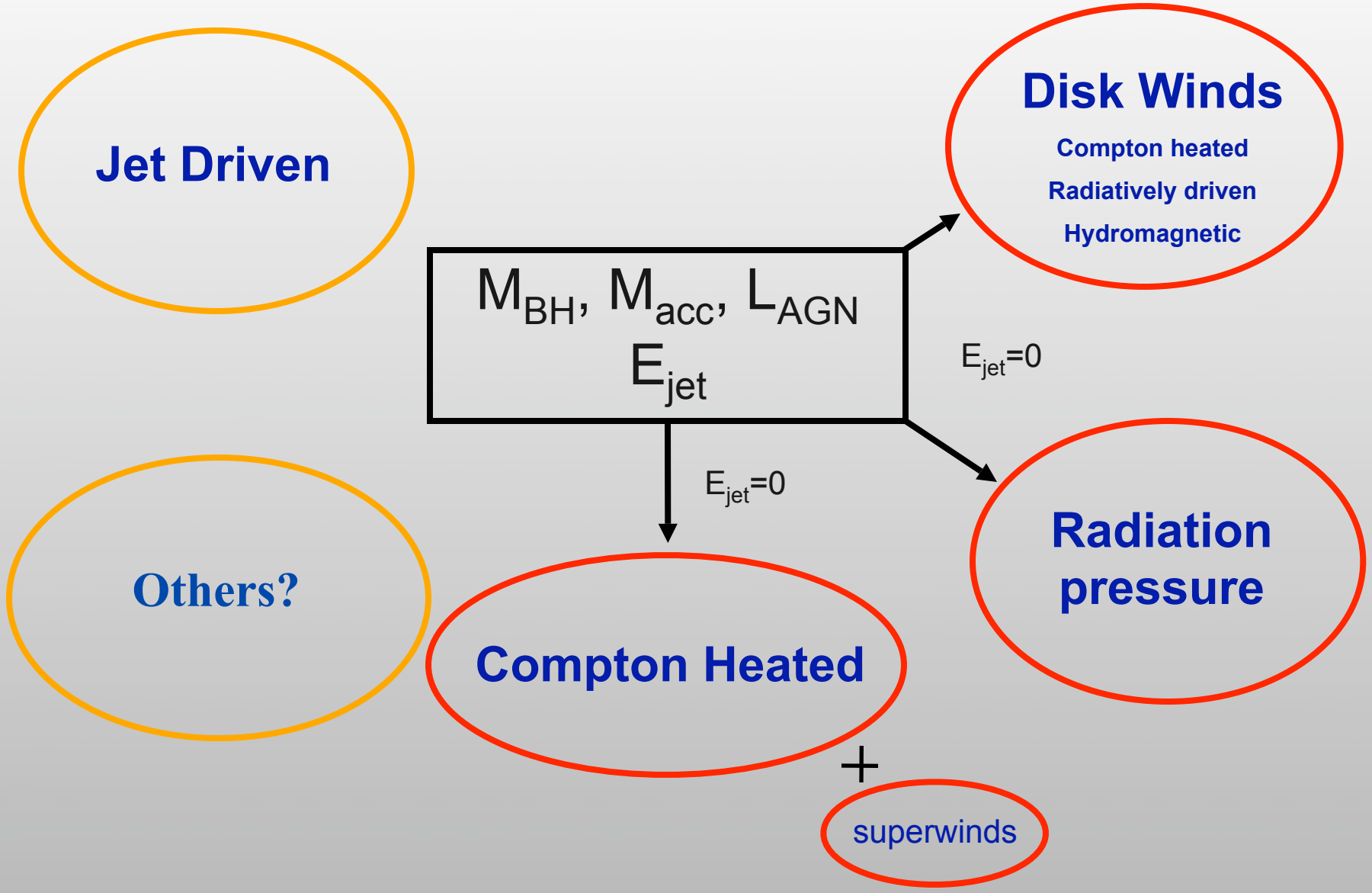
Is the feedback mostly positive or mostly negative? Would positive feedback solve the "coordination problem"?

When does maintenance dominate over exorcism?

Why is the coupling on many scales so good?

Are radio jets so rare as to not have a large impact on galaxies? Numbers are enough for clusters but are we missing jets?

Inputs to Outputs: RQ AGN



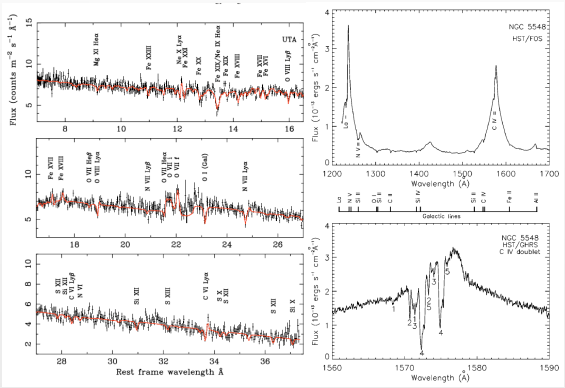
Radio-Quiet AGN

This is a much more challenging problem … apparently

1. Investigate the UV/X-ray absorption lines to estimate the outflow rates, energies, etc.

2. As with the radio-loud sources, look for the impact of such outflows on the surrounding ISM/ICM/IGM.

"Winds" in RQ AGN:Methodology



X-ray/UV spectra

L_{bol}, $L(\lambda)$, $\Delta L(\lambda)$, M_{BH}

EQW, FWHM, V

C_f, τ, N

$$U=\int L_\nu \, h\nu/4\pi r^2 nc \, d\nu$$

$$\Xi = L/4\pi r^2 cp$$

time lag/photo-ionization

$$t_{ion} = h\nu_t/F_{ion}\langle\sigma_{ion}\rangle$$

$$r_{ion} = F_{ion}/4\pi r^2$$

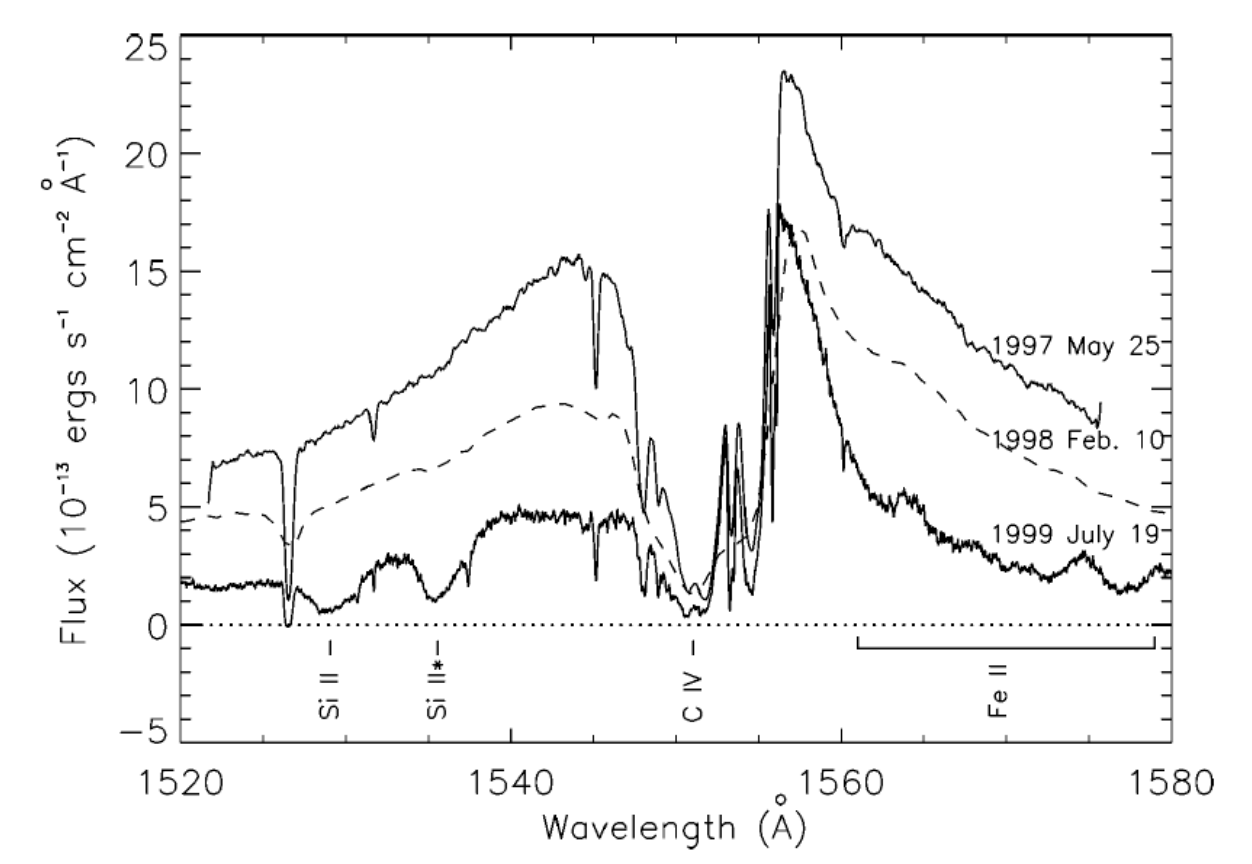
Log U=-4.0 to 1.0 (UV to X-ray)

$n_e = 10 - 10^9$ cm^{-3}

Multiphase medium of wide ionization and structure …

Outflows from Radio Quiet AGN

Variable absorption line profiles … tight constraints on U and N_H

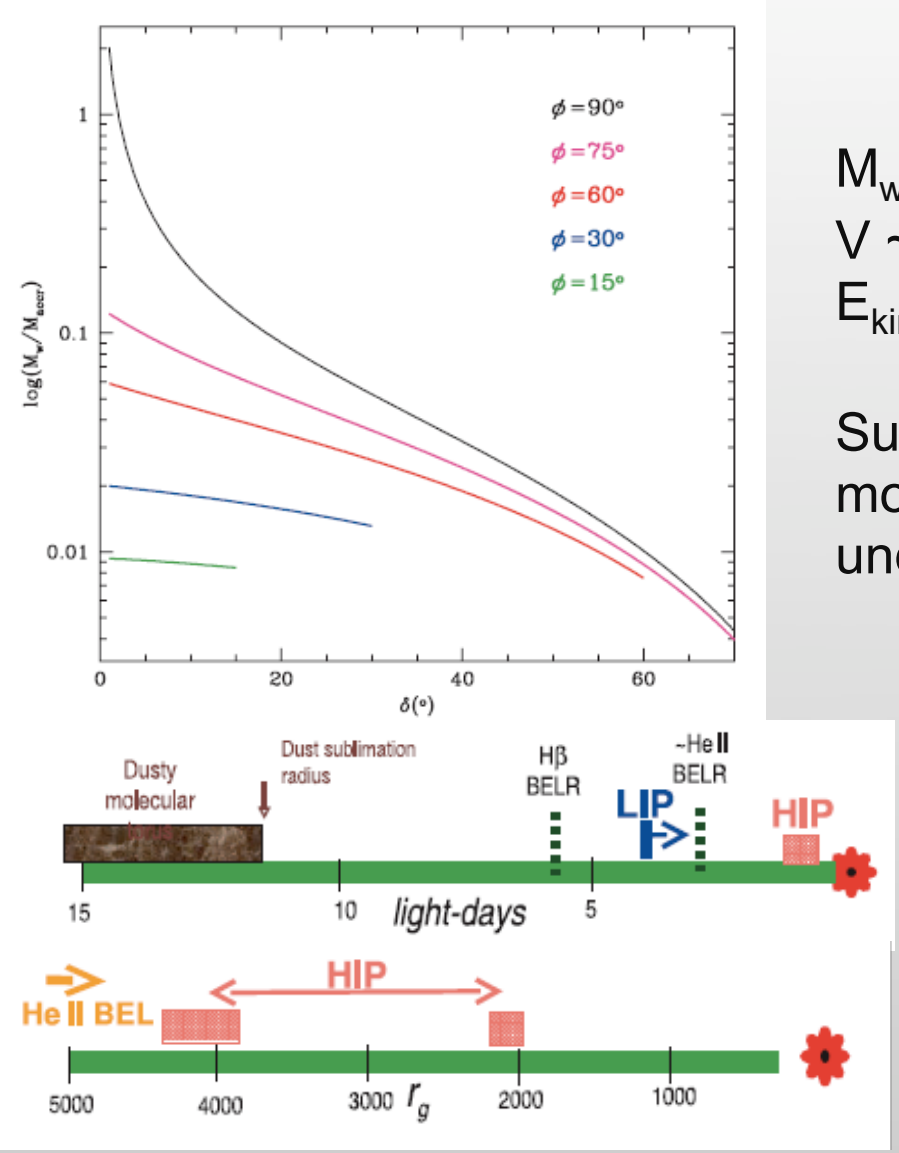


Changes likely due to both continuum variability, ionization, and motions

Crenshaw, Kraemer, & George (2003)

Outflows from Radio Quiet AGN

Detailed look at Sy NGC 4051 … finds slow wind with low mass outflow rate



M_{wind} ~ 0.02-0.05 M_{acc}

V ~ 500 km s^{-1}

E_{kin} ~ 10^{54} ergs

Suggest that can make these more effective, may be underestimating the velocities …

Korngold et al. (2007)

Summary of RQ AGN "winds"

Have intrinsically low mass loss rates: ~0.01 - few $M_\odot$ yr^{-1}

Anywhere from few % to 500% of mass accretion rate

$M_{abs} >> M_{BLR}$

Outflow velocities have wide range: 500-5000 km s^{-1}

Lauch radius: within a few light days, more for more luminous sources

Kinetic energies: $10^{42\text{-}45.3}$ ergs s^{-1} or 0.01-1 L_{bol}

From Seyferts to QSOs: Bulge heating to galaxy heating?

Results are difficult to obtain given the S/N that is needed to do the full modeling …also there is a lot of diversity in making these estimates with the most vigorous outflows seen in broad absorption bands, e.g., Fe XXV, not discrete features

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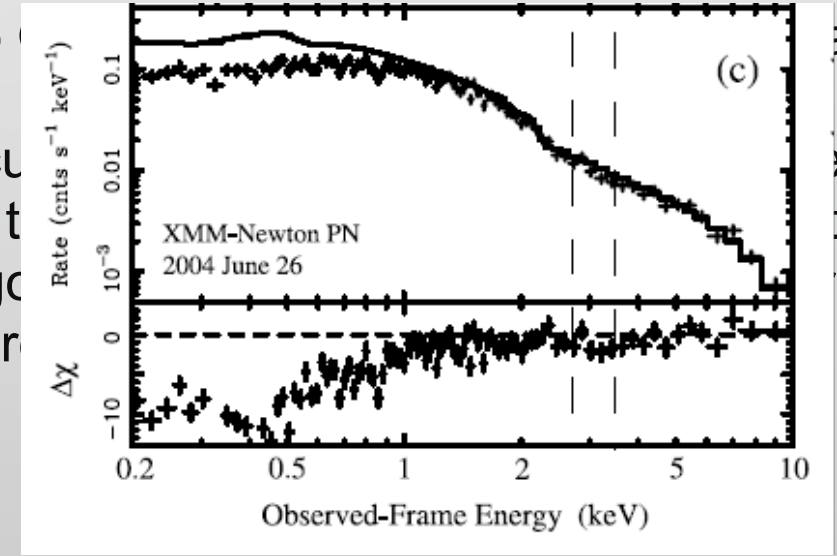
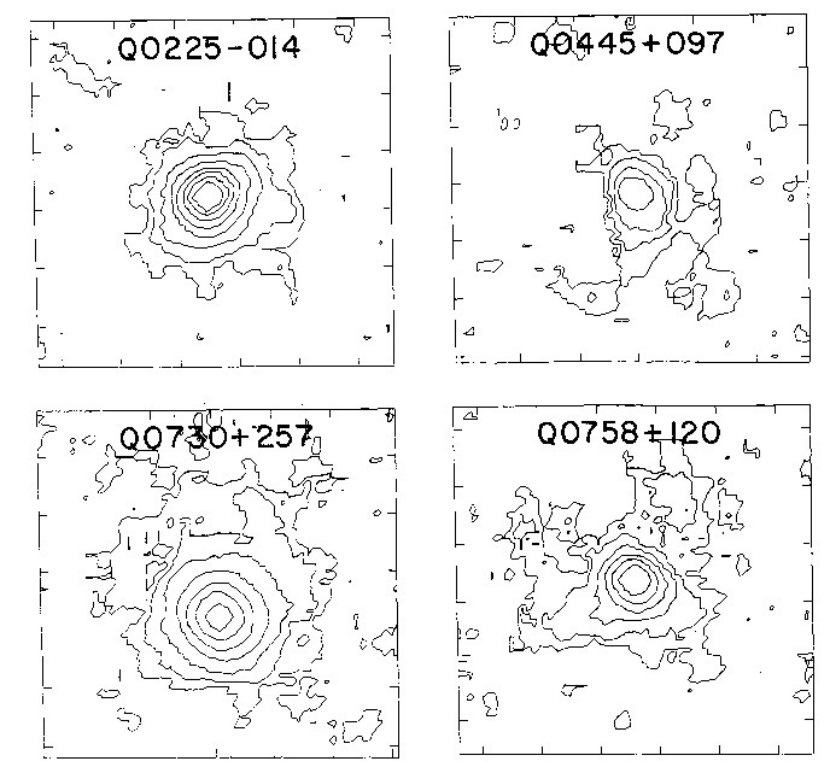
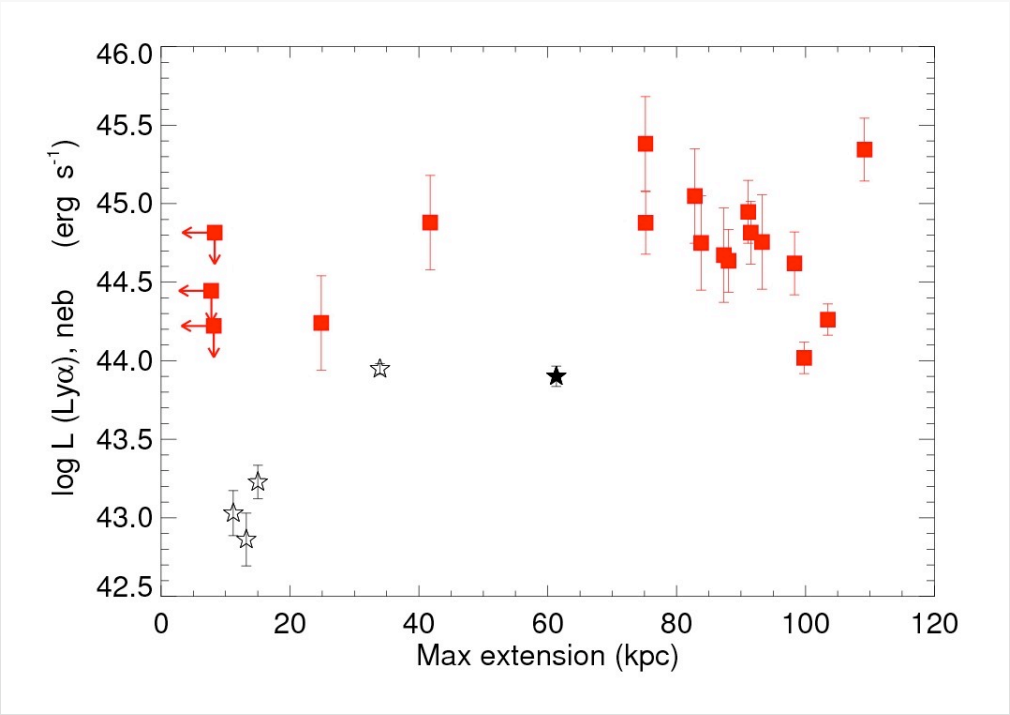


Chartas et al. 2007

Evidence at Larger Scales?





Heckman et al. 1991a,b; Christensen et al. 2006

… really related to outflows … more energetic/massive inflows
… cluster versus field environments … something else …

Questions about Winds in RQ AGN

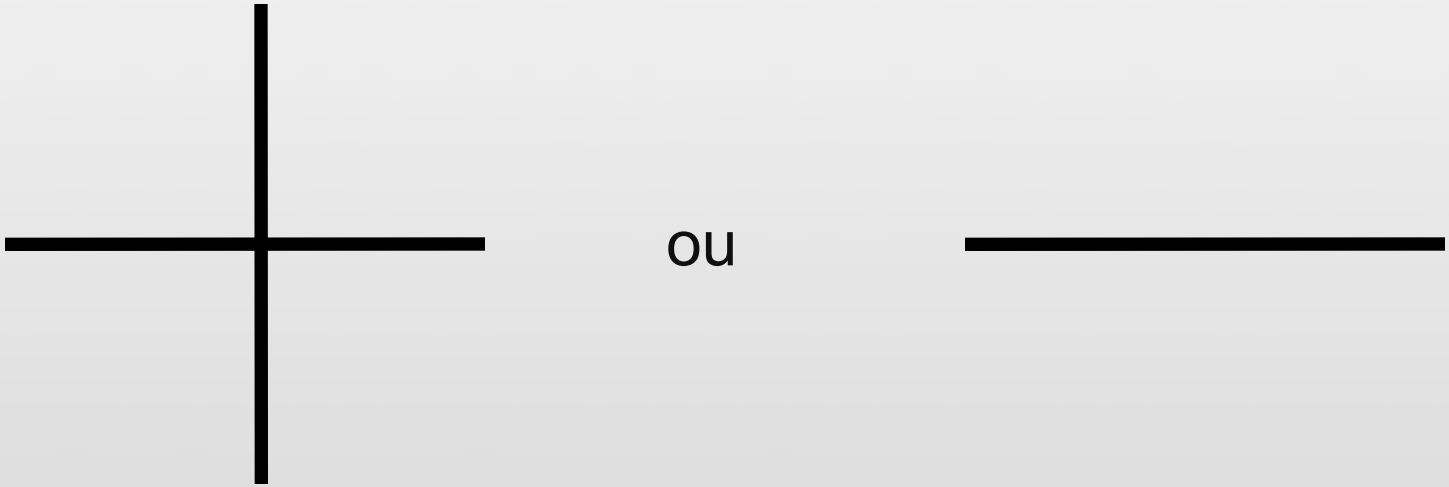
What is the launch radius of the wind? What's the role of gravity?

What is the time evolution of the wind? Since it is a light wind, few solar masses per year, how does it maintain its energy and momentum?

Why don't we see obvious signs of outflow at large radii as in radio loud sources?

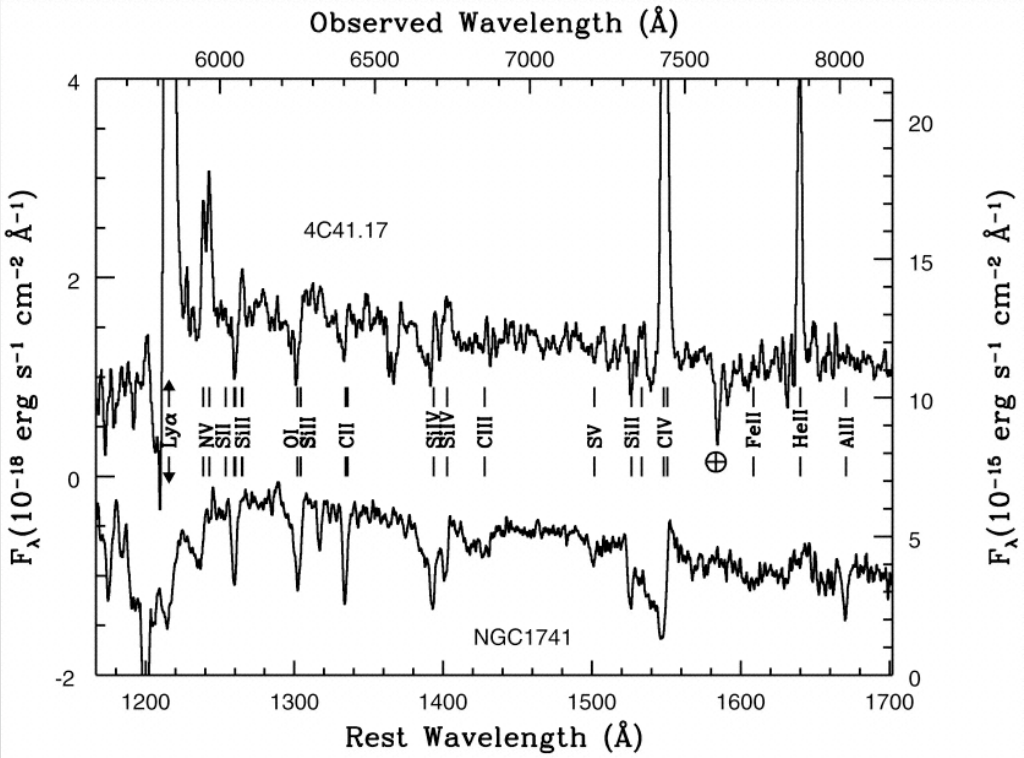
Why all of the apparently conflicting rates? Bursts, viewing angle, collimation, clumpiness, general ignorance, too few observations???

What is the "action" of feedback?



Feedback: Positive or Negative?

Young stars in 4C 41.17 … young enough to be associated



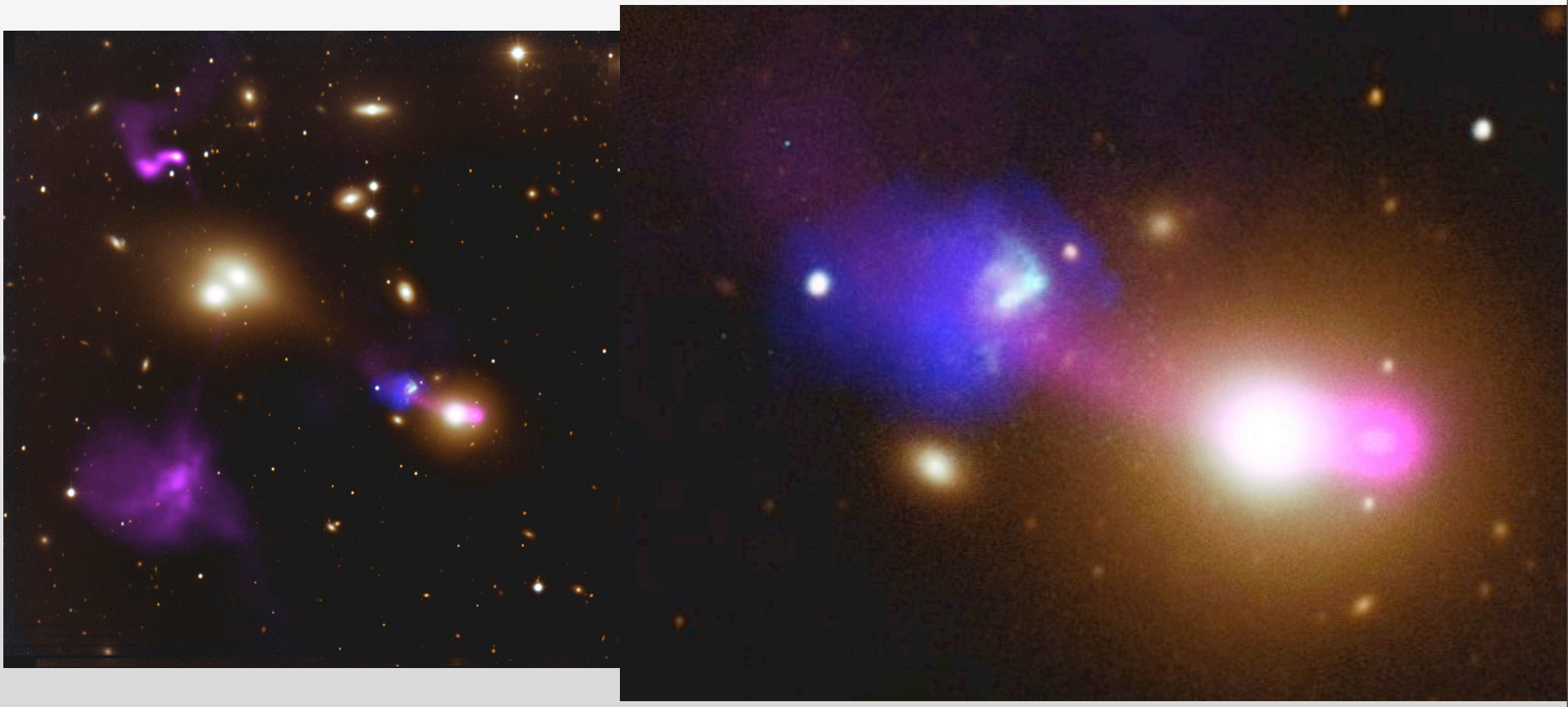
Dey et al. 1997

… but coincident does not mean causal …

something more direct?

Feedback: Positive or Negative?

The Nature of Minkowski's Object …0.5 $M_\odot$ yr^{-1}, 5 x 10^8 $M_\odot$ in HI …

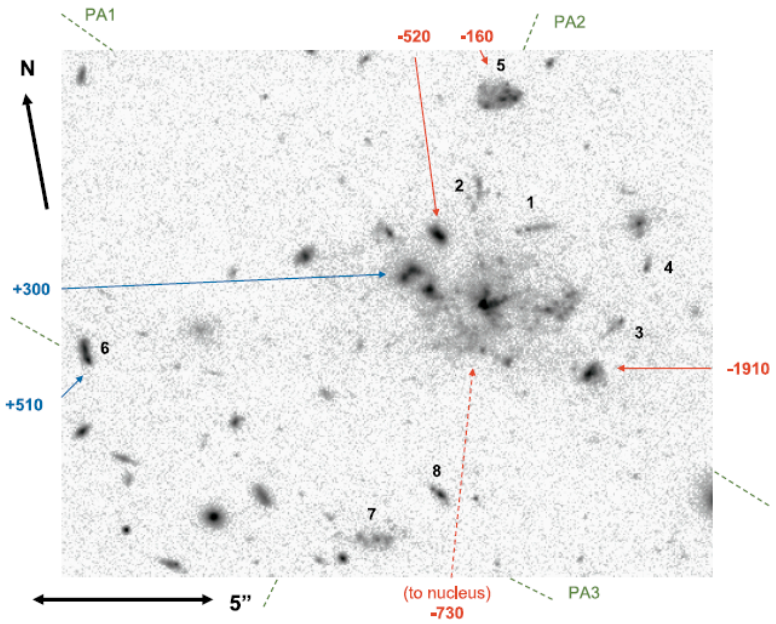


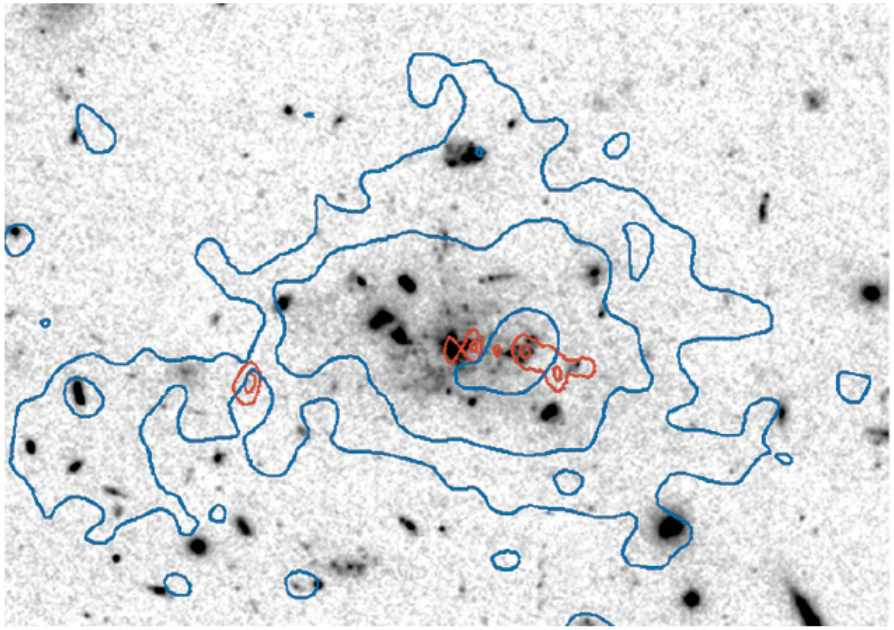
… young, jet passing through, dense gas … small but important
…are dense clouds compressed like this at high-z?

Croft et al. 2006

Feedback: Positive or Negative?

Young galaxies around MRC1138-282 …





Miley et al. (2006)

… the young galaxies embedded in the gaseous halo … are they the high-z Minkowski objects that merge to form a galaxy?

Conclusions

We know that radio jets can influence gas on all scales – both *maintenance and exorcism*.

But: do all AGN have a radio loud phase? Is the feedback mostly negative or positive? *Negative easy.*

AGN without substantial radio emission drive winds. Such winds are “light” and susceptible to strong losses. Not clear what is the *driving mechanism*.

Radio-quiet AGN are not radio dead. Weak jets have some influence.

Why don’t we see more obvious evidence at large scales for outflows in RQ AGN?