Observations of Feedback in Radio-Quiet Quasars

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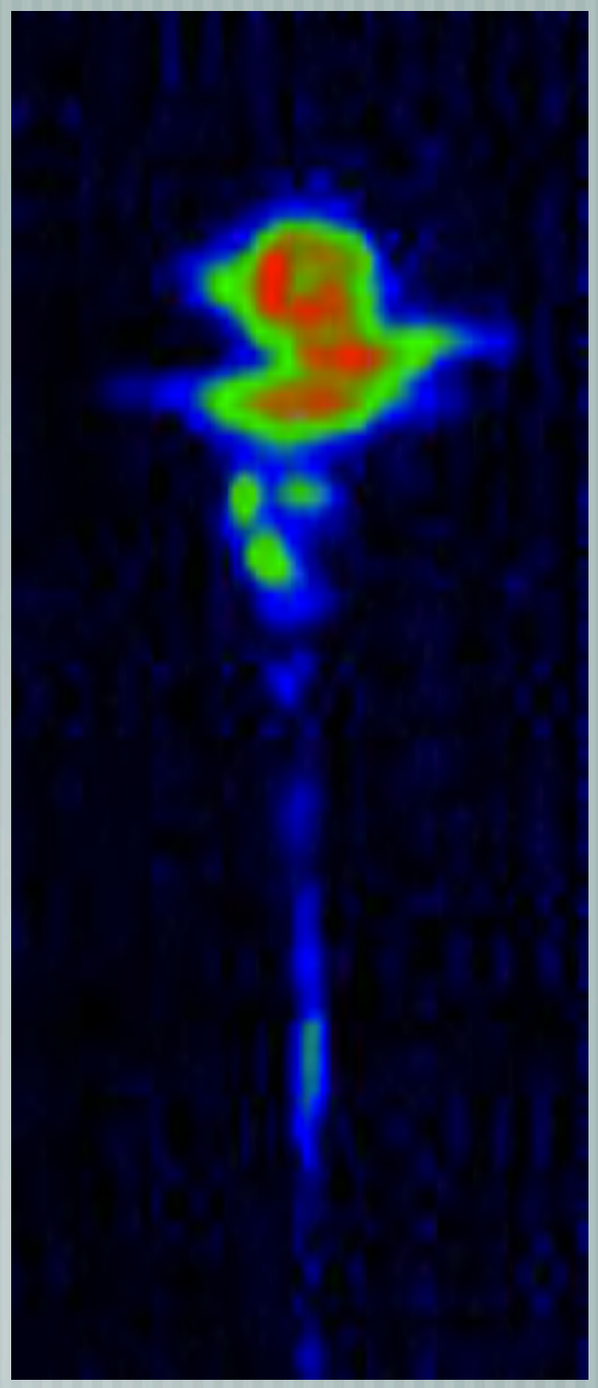
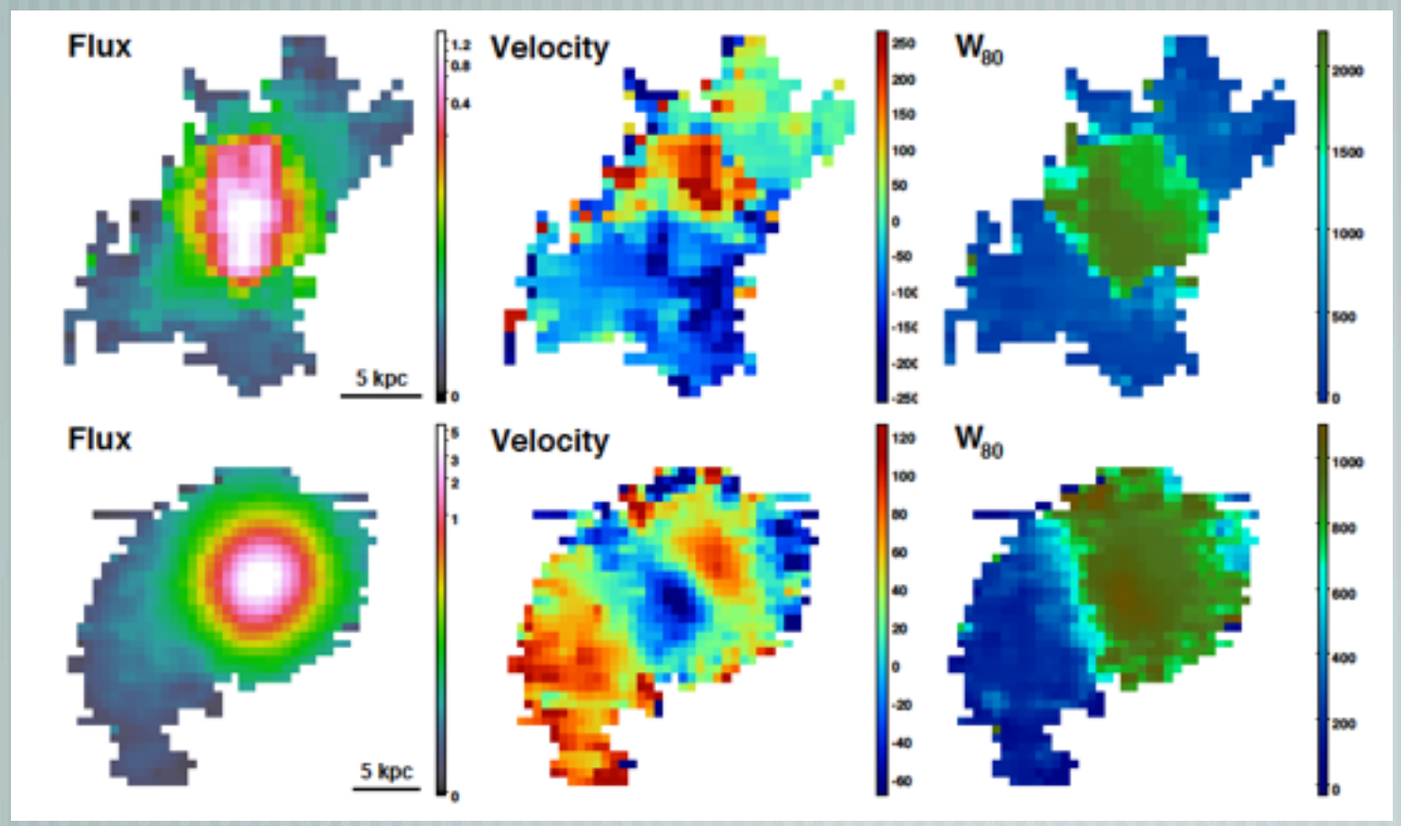


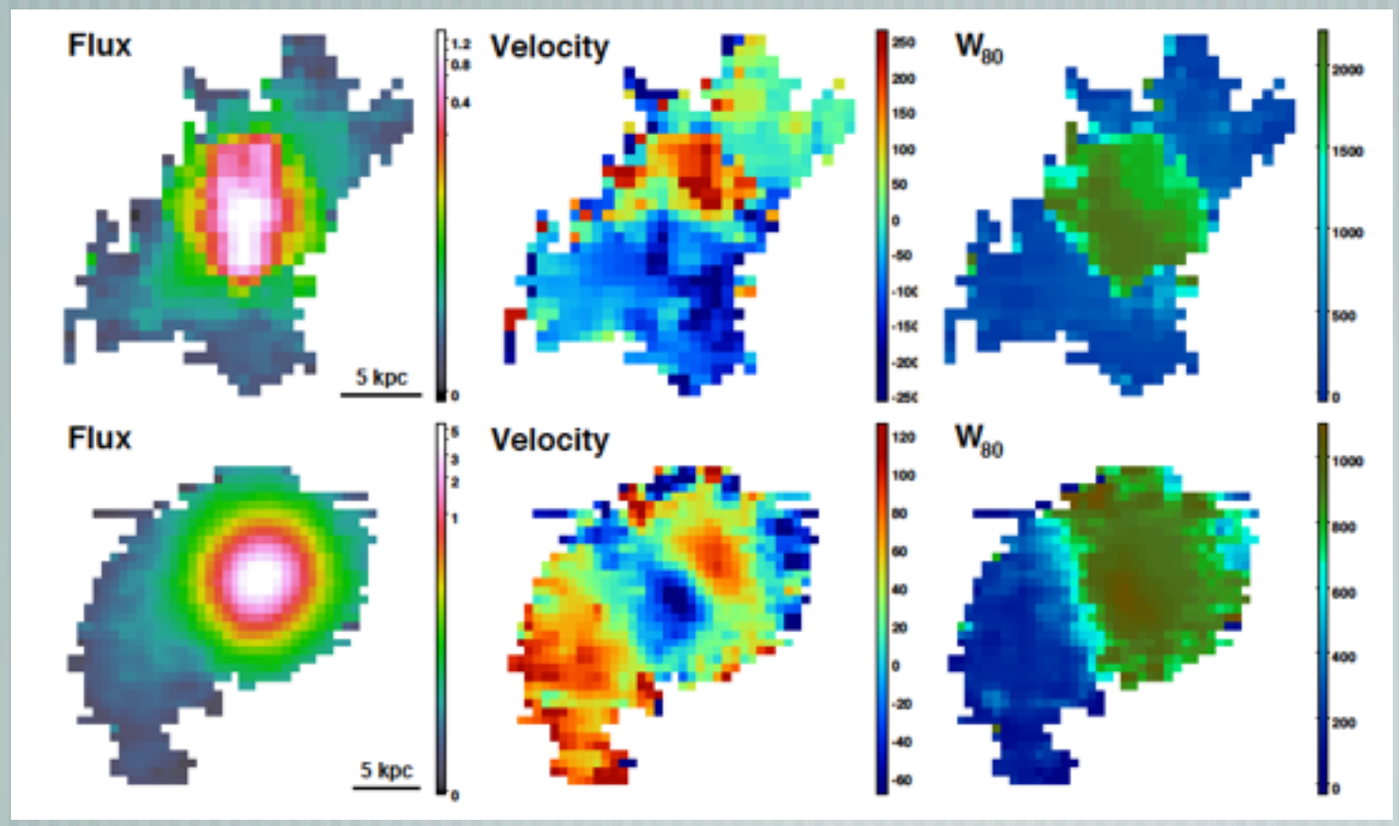


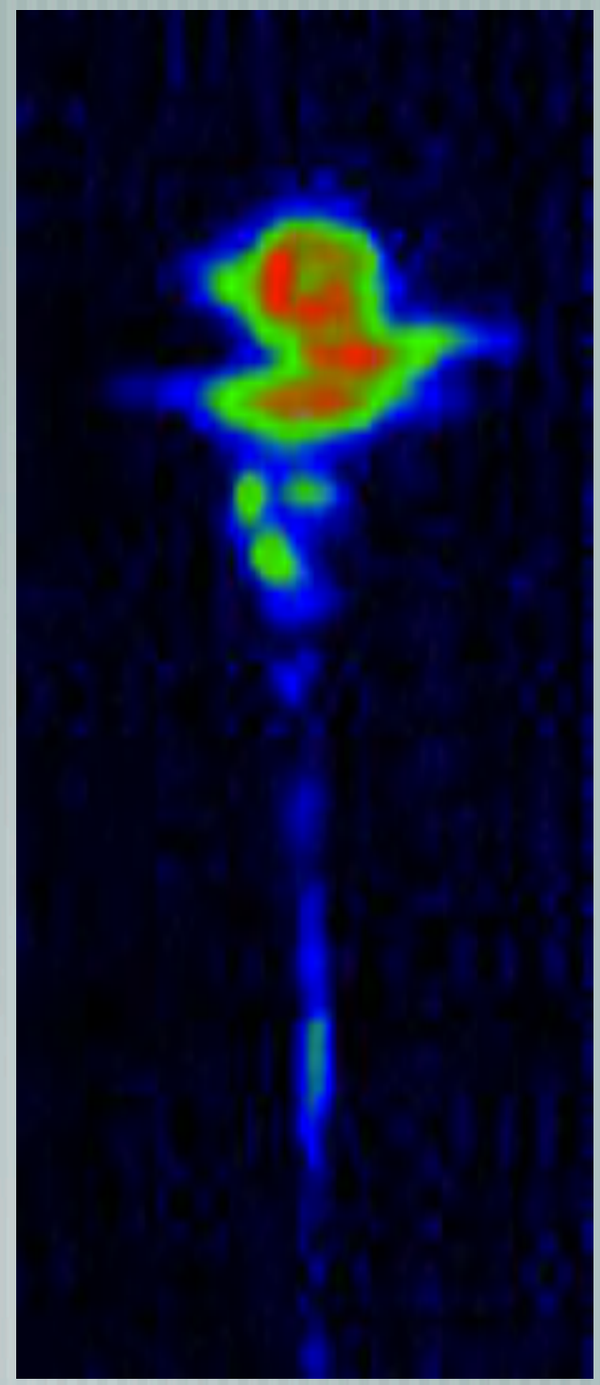
Observations of Feedback in Radio-Quiet Quasars

– Why radio-quiet?

– Observations of multi-phase quasar winds

– Bridging theory and observations



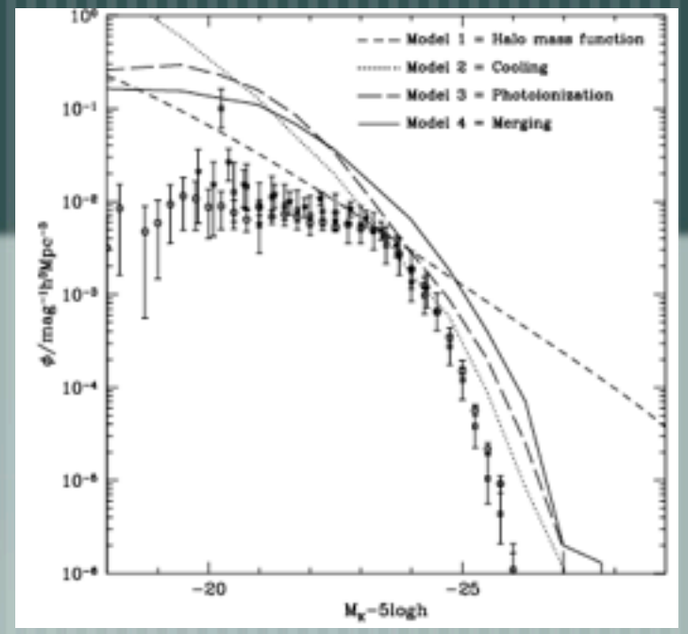


1. Why Radio-Quiet?

Negative quasar feedback in most of the massive galaxies

Galaxy luminosity function, colors

Black hole / bulge correlations



Benson et al. 2003

Only 10% of AGN currently have very powerful jets

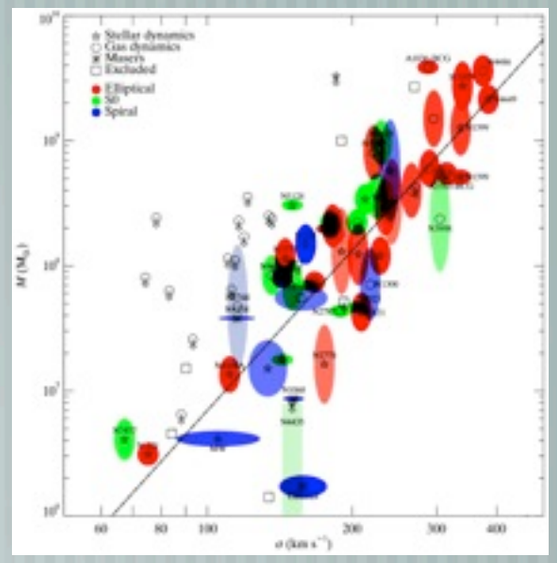
(Intra-cluster medium – might be enough)

(unclear what's going on at high redshift z=2, luminosity dependence?)

Perhaps every galaxy had a powerful jet once?

But: differences between haloes of RL and non-RL objects (Mandelbaum + 2009).

Perhaps weak jets are sufficient to drive feedback?



Gebhard et al., Ferrarese & Merritt 2000, Tremaine et al. 2002, Gultekin et al. 2009

1. Why Radio-Quiet?

There is a known mechanism for RQ feedback

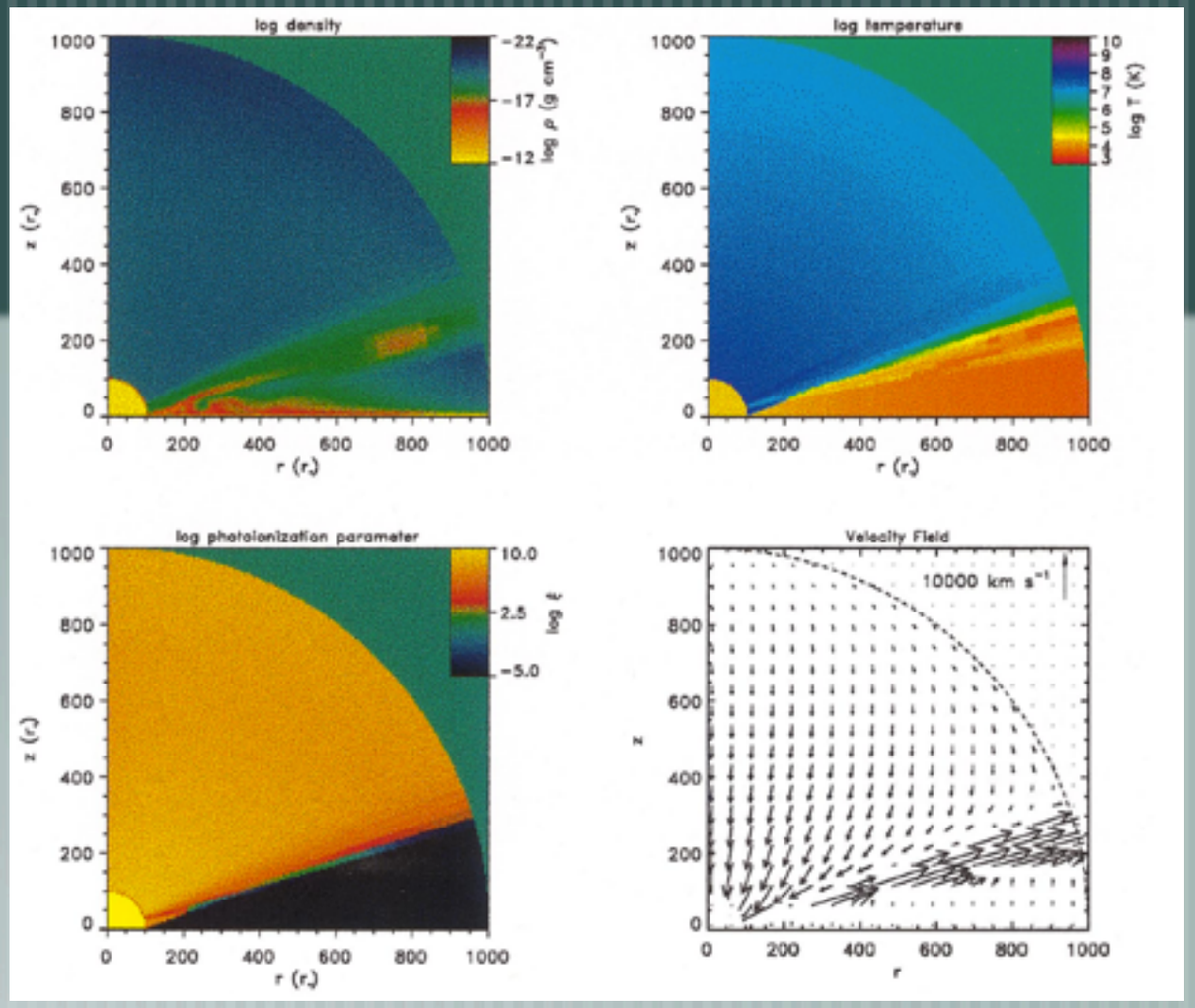
"Line driving"

"Radiative driving"

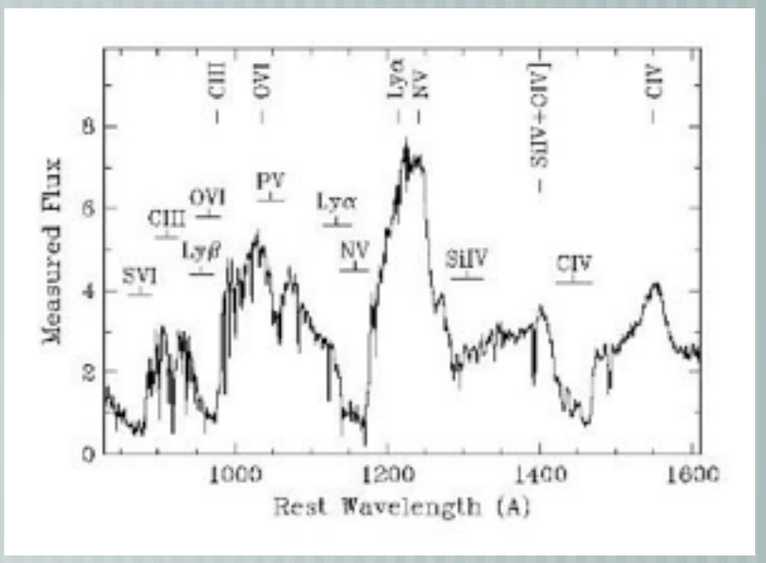
Small scale outflows seen in 20% of RQ quasars

Do they do enough on galaxy-wide scale?

Quasar – acceleration close to the nucleus – fast gas runs into ISM

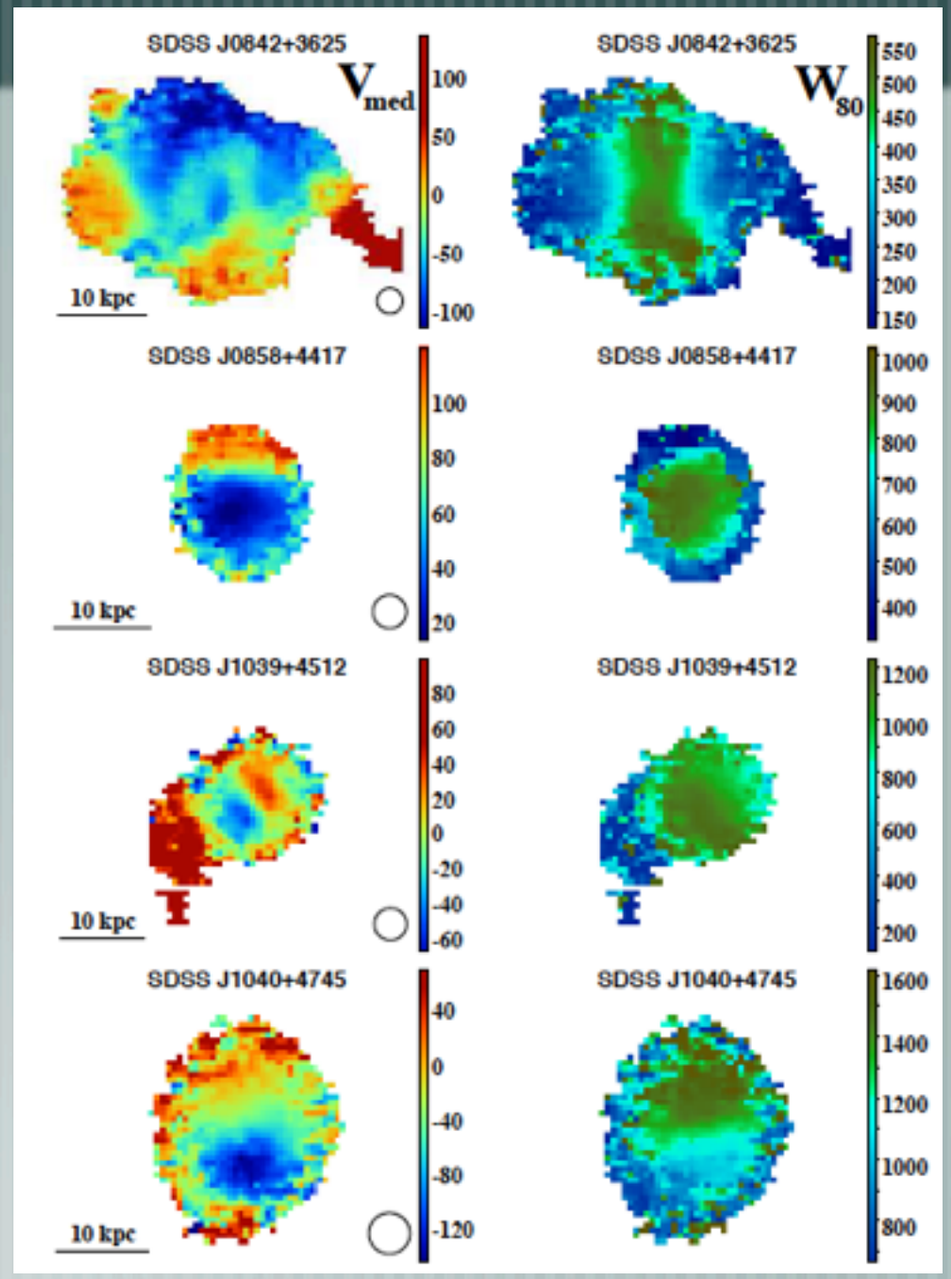


Murray et al. 1995
Proga et al 2000



2. Observations of feedback in RQ quasars

- "Multi-phase" wind (presumably due to initial ISM, but maybe instabilities?)
- Every phase = its own observational signature
- If phases are in pressure equilibrium, $n_{hot}T_{hot}=n_{warm}T_{warm}=n_{cold}T_{cold}$
- Something hot and tenuous = volume-filling, everything else = clouds, filaments?

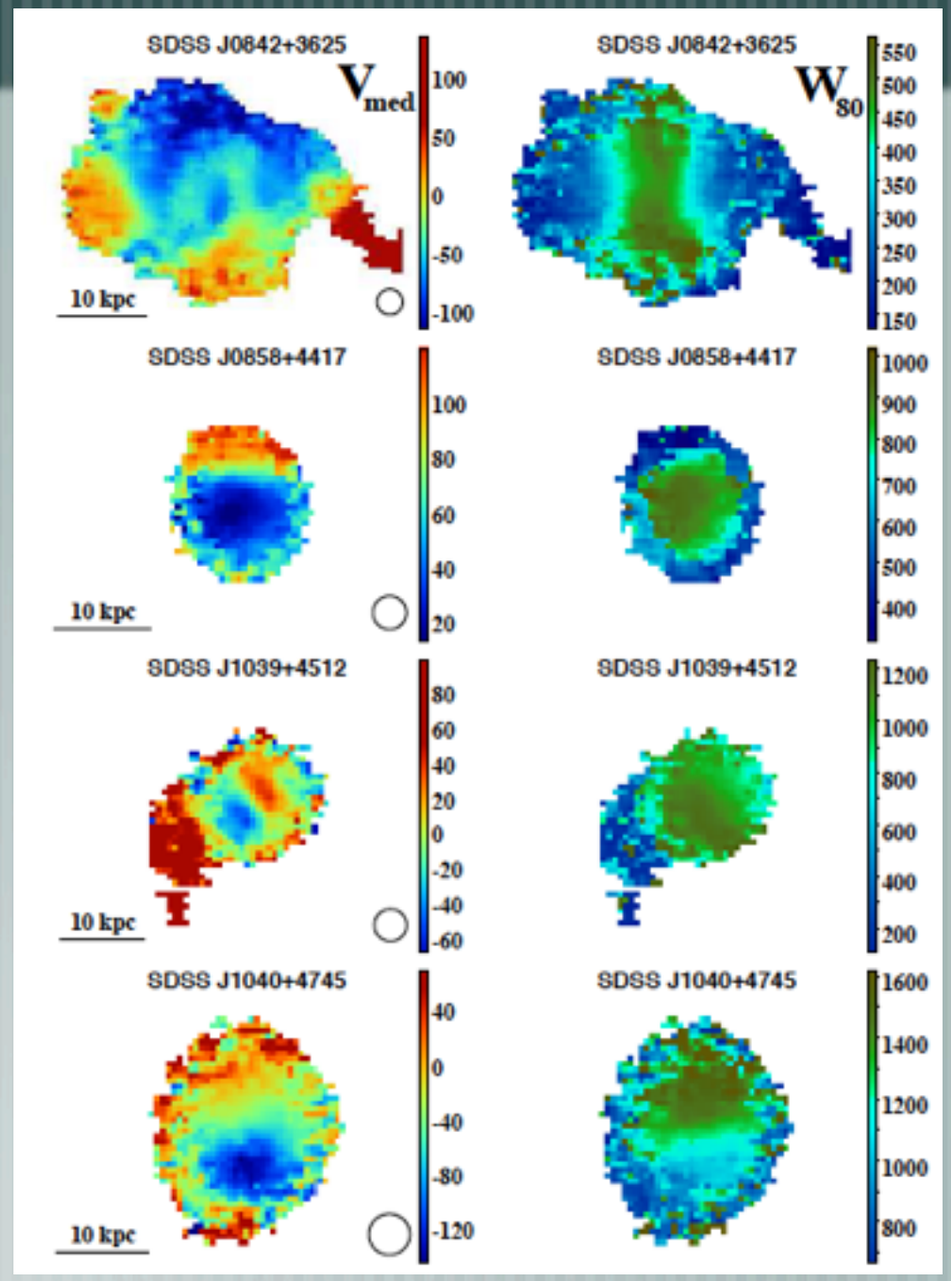


Liu, Zakamska, et al. 2013a,b,c

2. Observations of feedback in RQ quasars

warm ionized gas

- Line-emitting gas: can study kinematics
- T=10^4K, densities from <10 to >100 cm^{-3}
- Integral field unit observations – spectrum in every point
- Detect ionized gas to 15-40 kpc from the center in most cases
- Striking observational difference: RQ=round, RL=elongated



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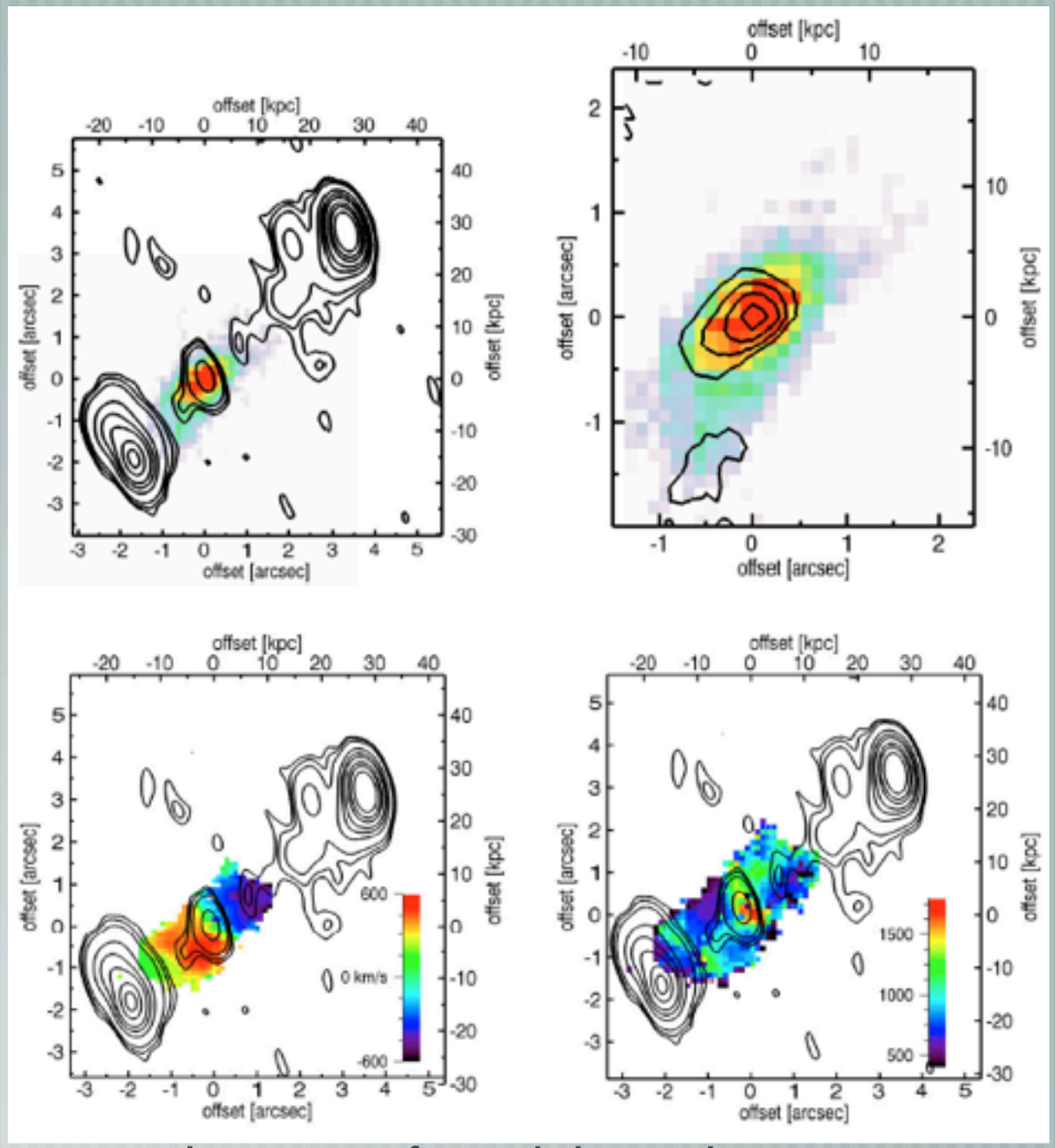

Observations of extended ionized gas, z=2-3
Nesvadba et al. 2006/08, M=10^{10}Msun, v>800km/s

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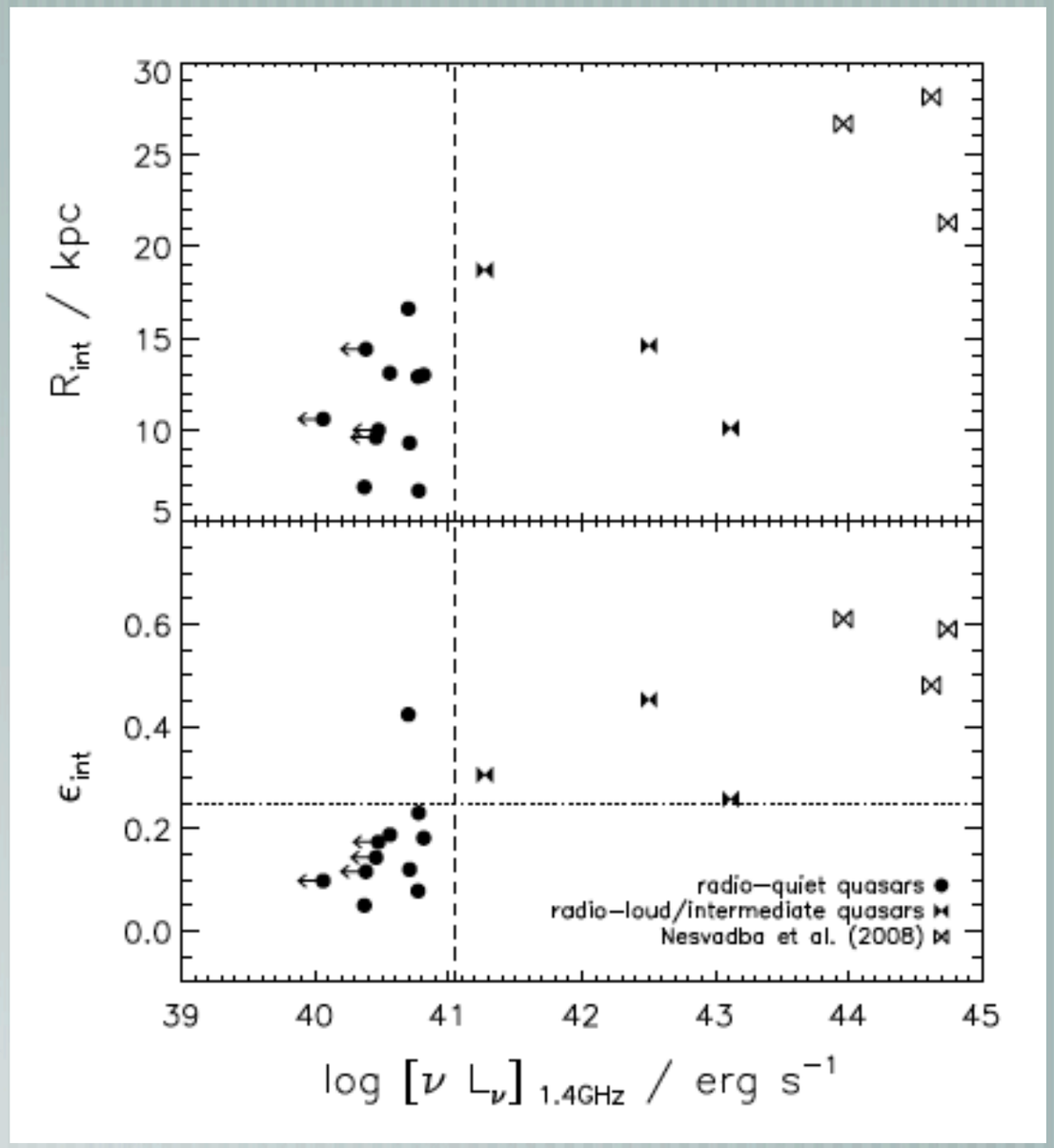
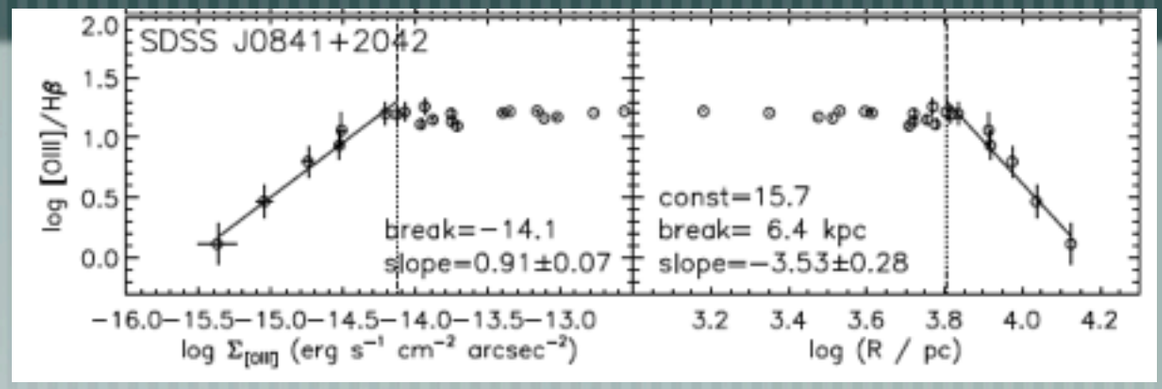


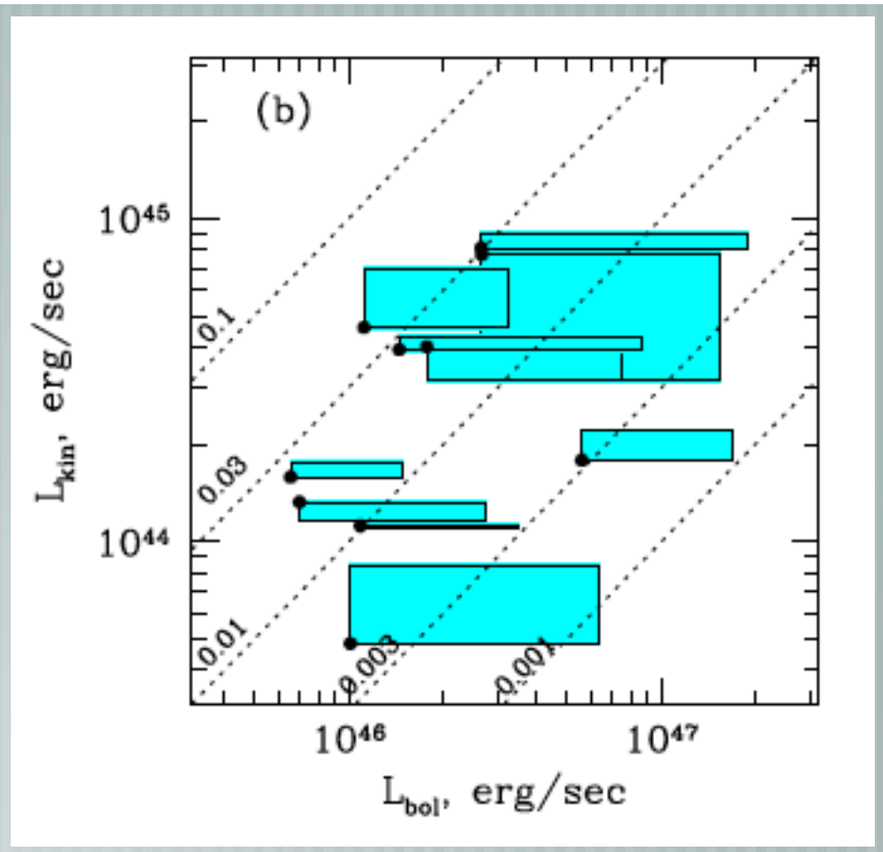
Liu, Zakamska, et al. 2013a

2. Observations of feedback in RQ quasars

warm ionized gas

- Line ratios: Clouds are getting more diffuse further out?
- Get "fried" ("matter-bounded")?
- Kinematic models: reproduce velocity maps, velocity dispersions, v_{out}=800km/sec
- This allows us to estimate kinetic energy flux
- Median is 2% of bolometric
- Uncertain... Need better models for volume-filling wind, cloud emission





Liu, Zakamska, et al. 2013a,b

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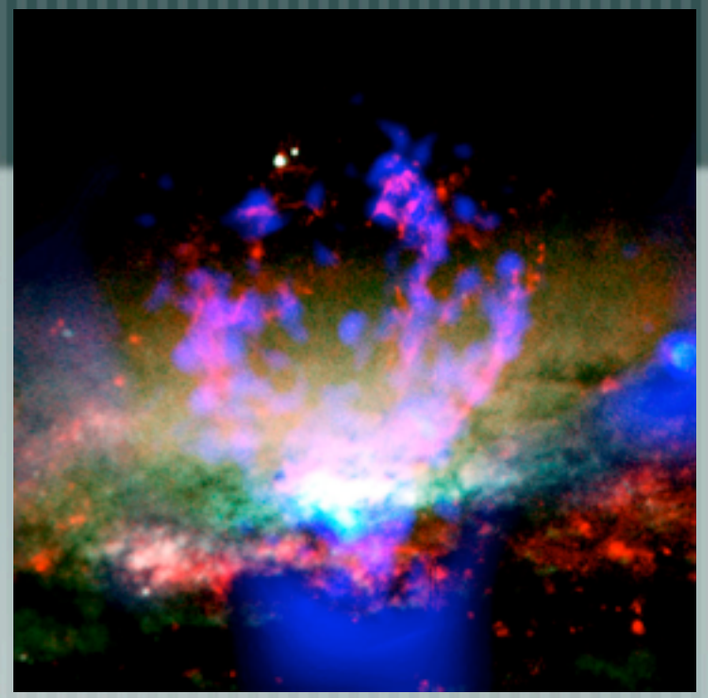
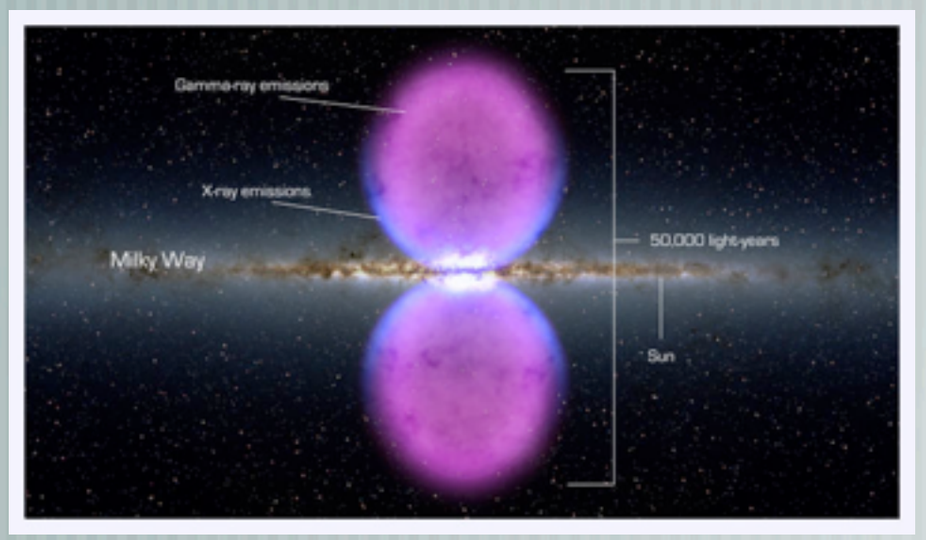
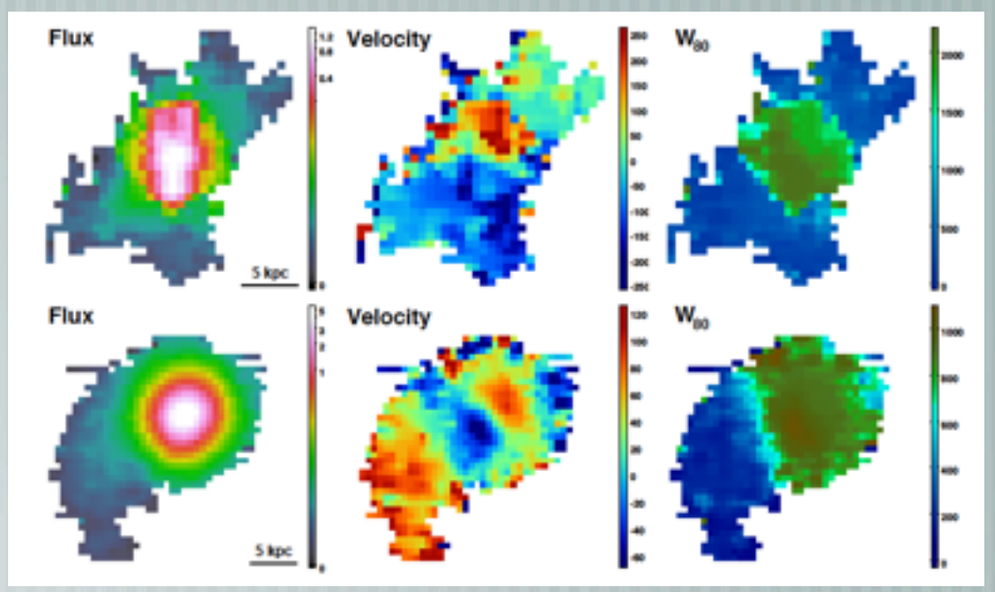


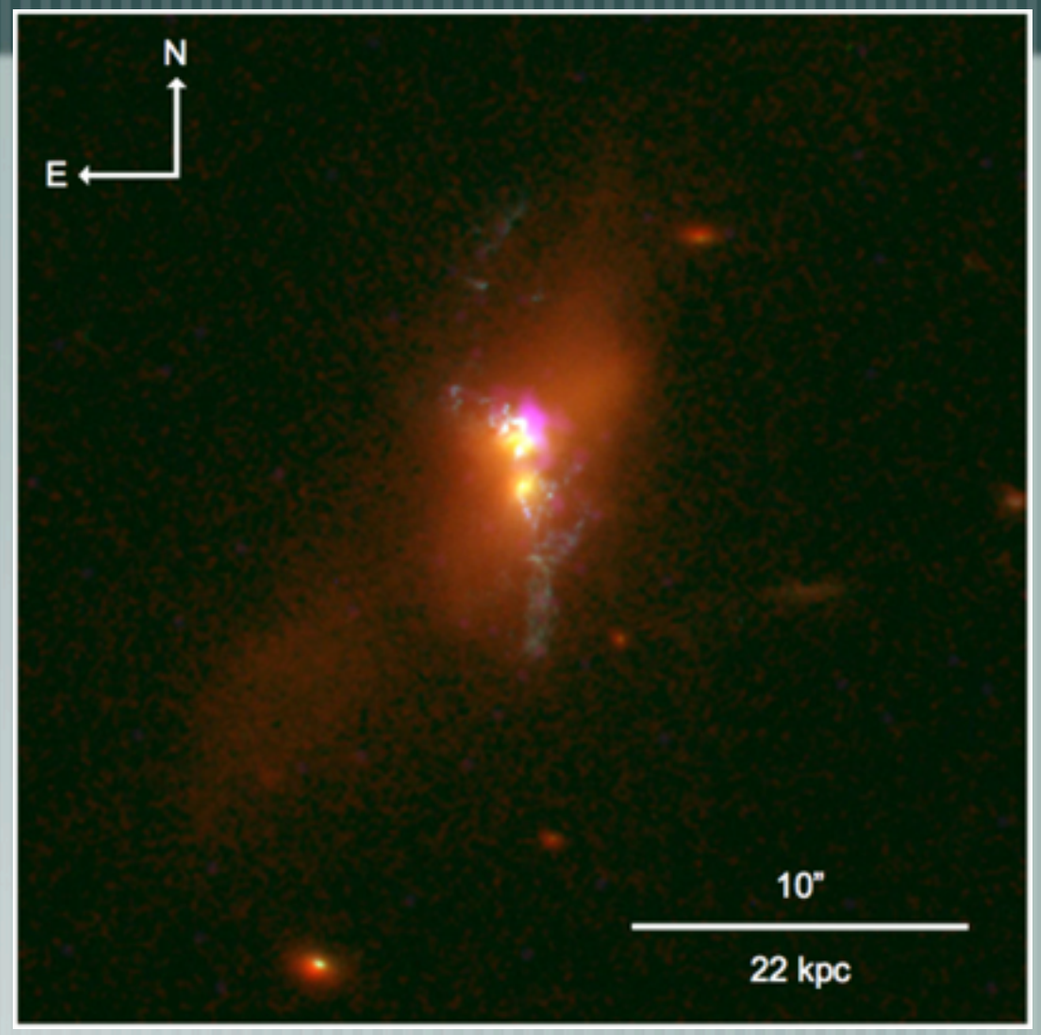
- A few candidates for super-bubbles
- Wind expands along the path of least resistance, perpendicular to disk
- starburst galaxies, Fermi Bubbles, simulations





2. Observations of feedback in RQ quasars
clouds and hot volume filling gas

- Warm ionized gas: too far to see individual clumps, filaments?
- See 20 pc clouds in HST images in one nearby object!
- Observed with every telescope on the ground and in space... (talk by Ai-Lei Sun this afternoon)
- Extended X-ray emission – hot volume-filling component? or shocked clouds?
- Low-density component: very hard. Could use predictions from simulations!



HST composite
Comerford et al.

Greene, Zakamska, Smith 2012

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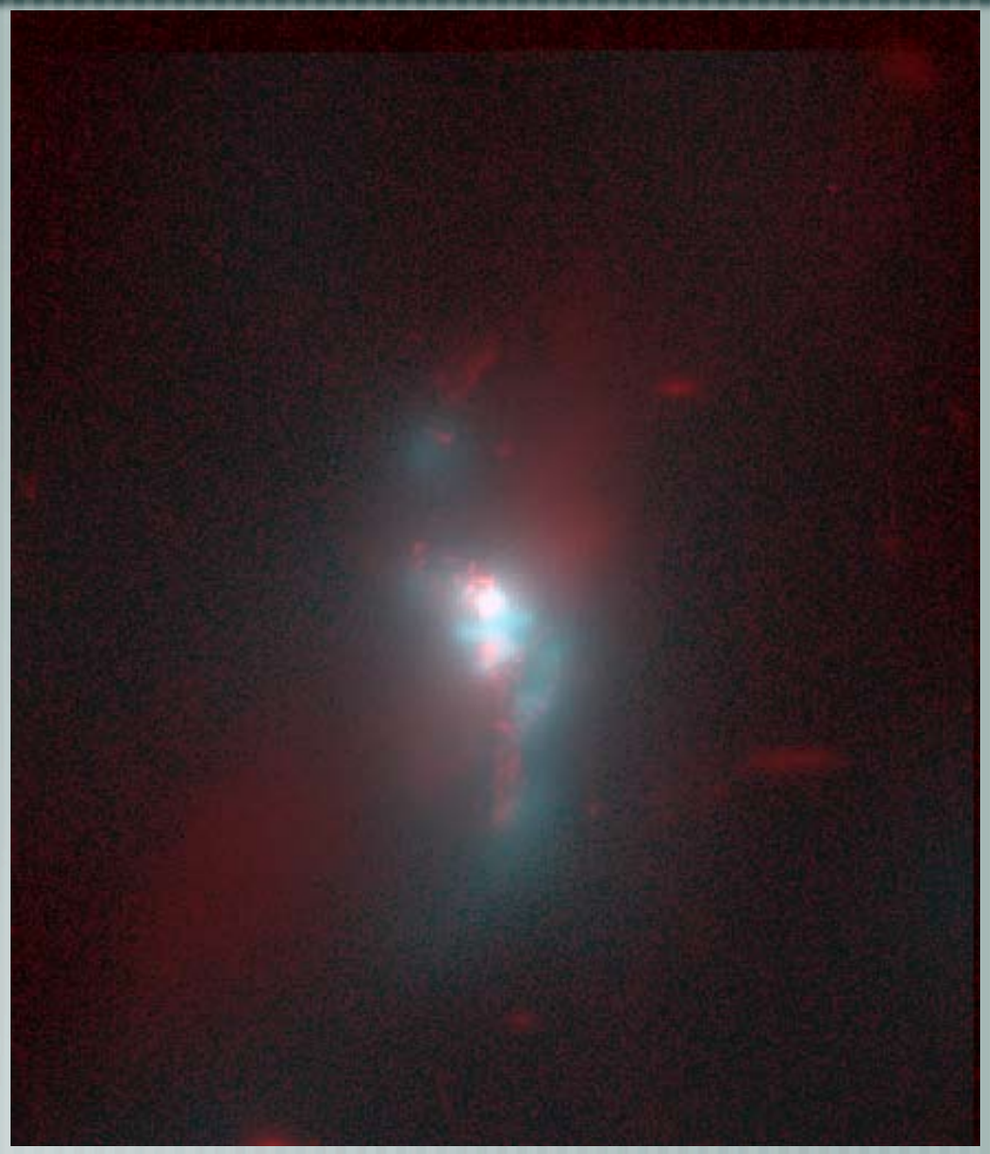
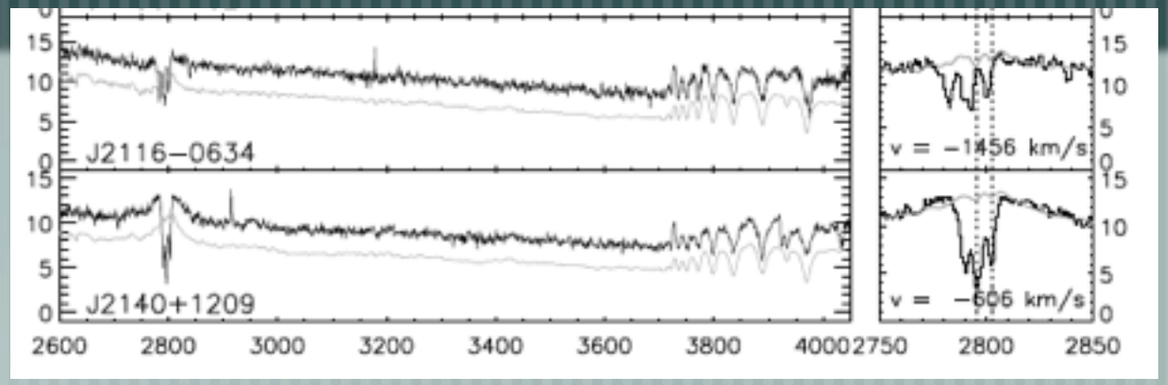


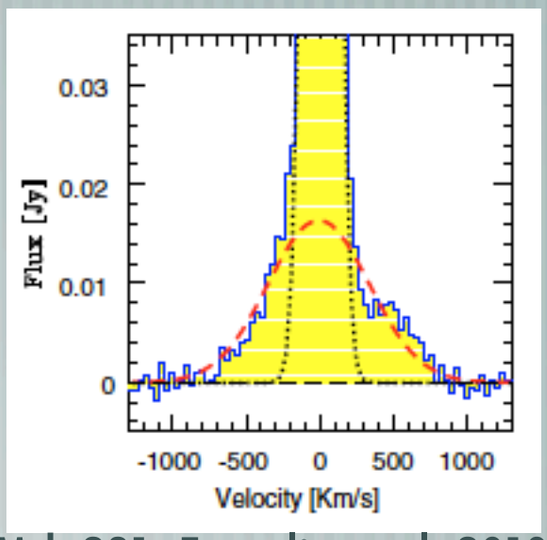
Chandra + HST-814
Pooley, Comerford, Greene, Zakamska

2. Observations of feedback in RQ quasars
colder phases

- Very important: dominate mass, energy?
- Cold neutral gas seen in blue-shifted absorption against the quasar
- Less common in quasars than in starbursts?
- Molecular gas seen with large velocities (inconsistent with disk)
- ALMA: In progress...



Tremonti et al. 2007 (these are not currently luminous quasars)

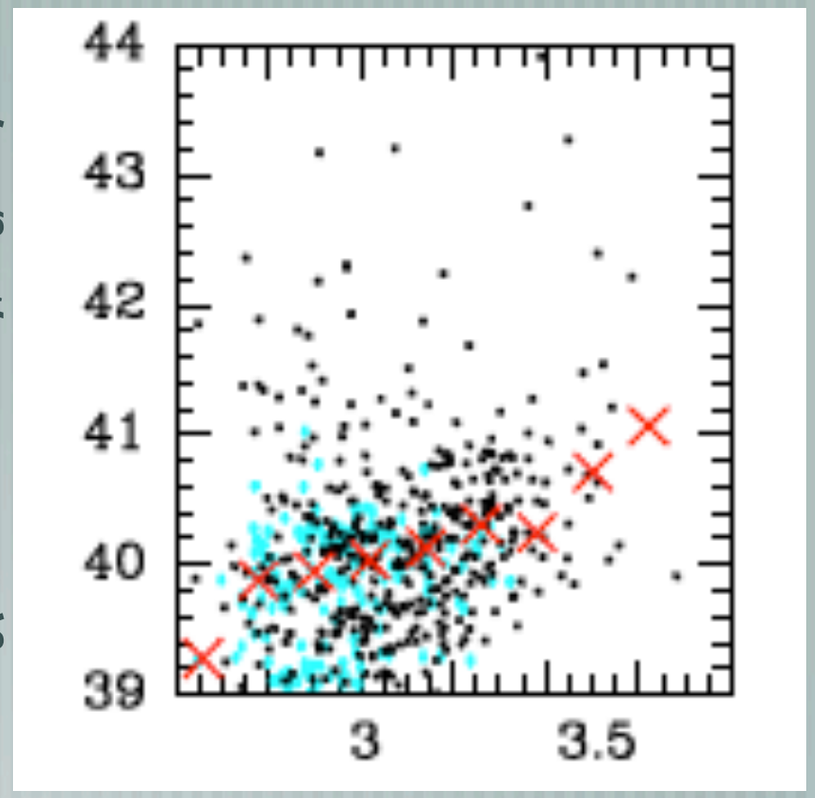


Mrk 231: Feruglio et al. 2010
CO emission, $dM/dt=710\ M_{sun}/year$
$E_{kin}=4.4x10^{44}$ erg/s, extended (3kpc)

2. Observations of feedback in RQ quasars

synchrotron emission?

- Like in a SNR: particles can be accelerated on the shock
- Expect radio synchrotron
- Strong correlation between velocity (from ionized gas lines) and radio luminosity

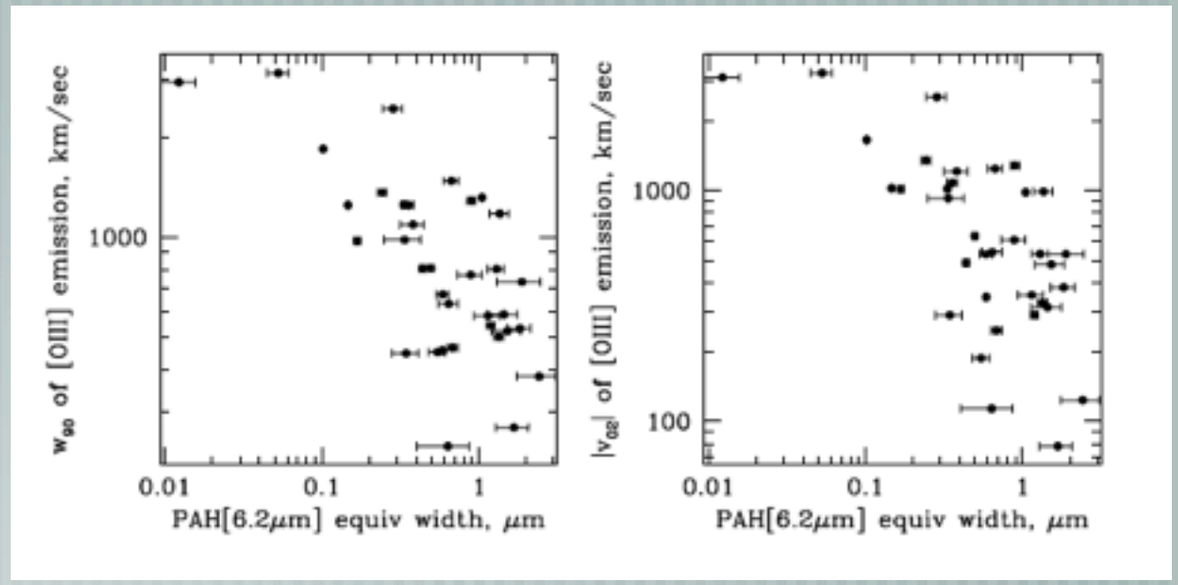


Zakamska & Greene, in prep.

2. Observations of feedback in RQ quasars

quasar vs star formation?

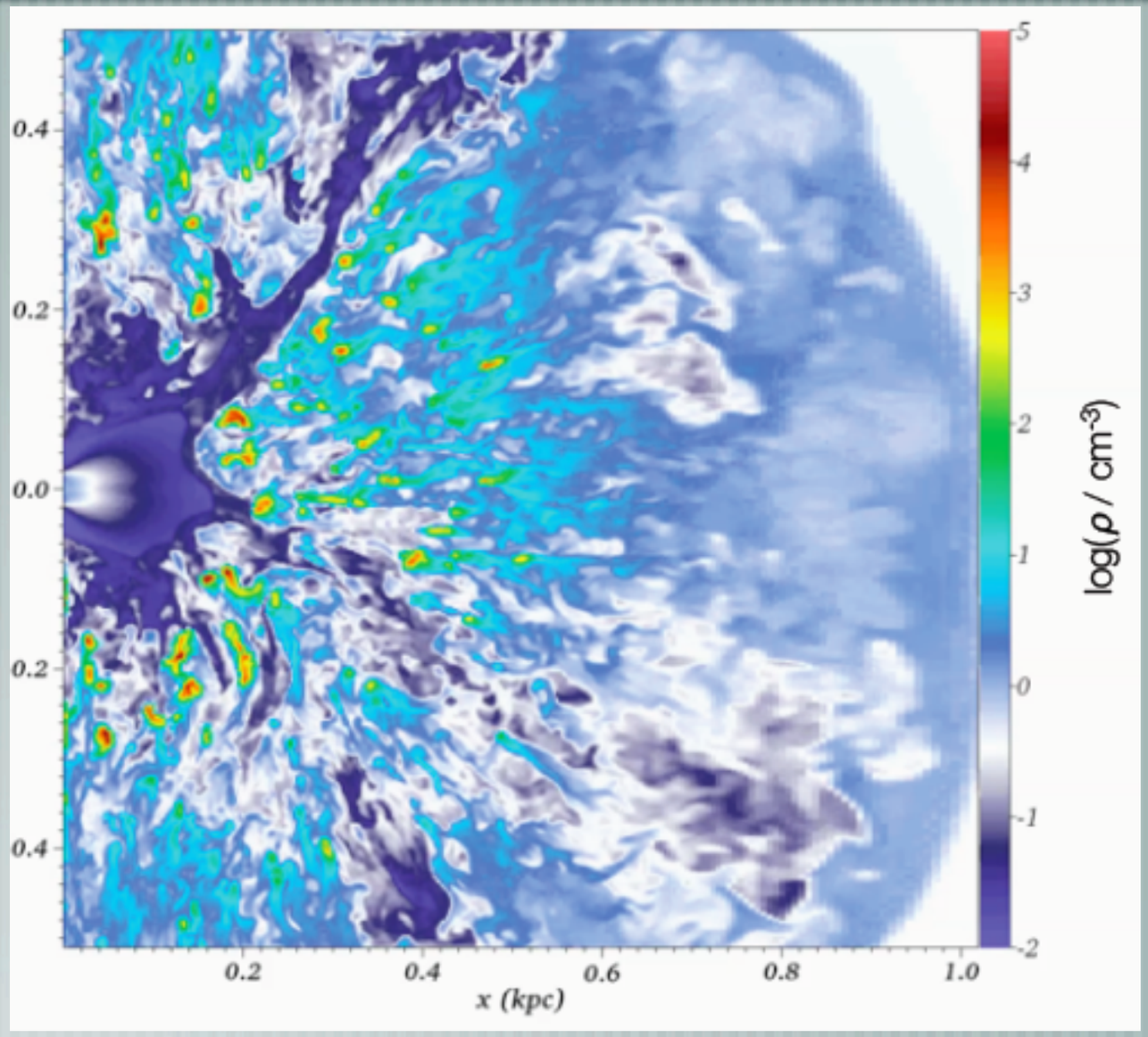
- Physics similar, how to distinguish?
- Considered local ULIRGs = quasars, starbursts and everything in between
- Winds in AGN-dominated objects faster (1000 km/sec) than in starbursts (500 km/sec)
- In mergers AGN phase shorter but more intense?
- Star formation insufficient on grounds of energetics



Hill & Zakamska 2013

3. Bridging theory and observations

- "Multi-phase" picture: wind runs into clumpy ISM
- Use simulations to predict emission from hot phase, warm phase
- Need radiative mechanisms (photo-ionization vs shock-ionization)
- Velocity fields of clumps are directly comparable! (Lots of kinematic information available...)
- Goal: reliable kinetic energies from observations



Thanks to Alex Wagner!

Summary

– RQ-mode feedback: isotropic "bomb" that sends a blast wave through galaxy ISM

– Different "phases" of the wind observable at different wavelengths

– Ionized gas (10^4K) – the most detailed picture so far

– Right about now is the time to compare with simulations!

– We are very interested!

– JHU: G.Liu, R.Alexandroff, O.Nayak, M.Hill

– J.Greene, A.-L.Sun, N.Nesvadba, J.Comerford