The cosmic evolution of radio-AGN feedback to z=1

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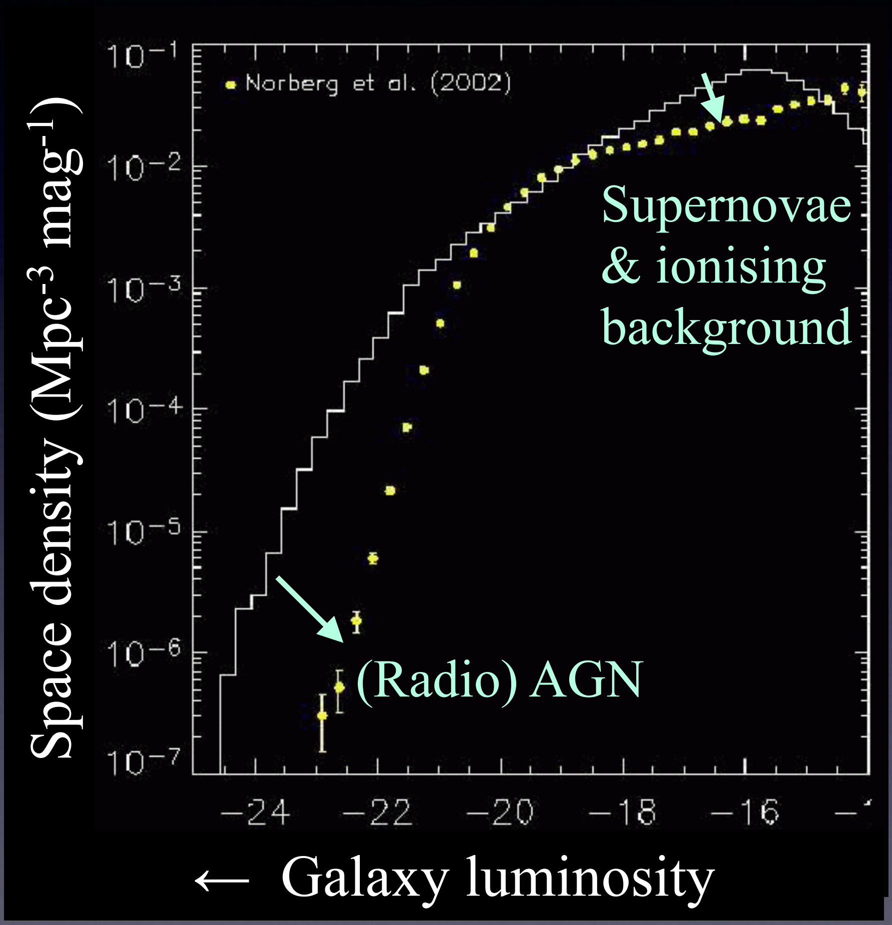
“AGN feedback” in galaxy models

Different modes of “AGN feedback” are currently postulated to explain many issues in galaxy evolution

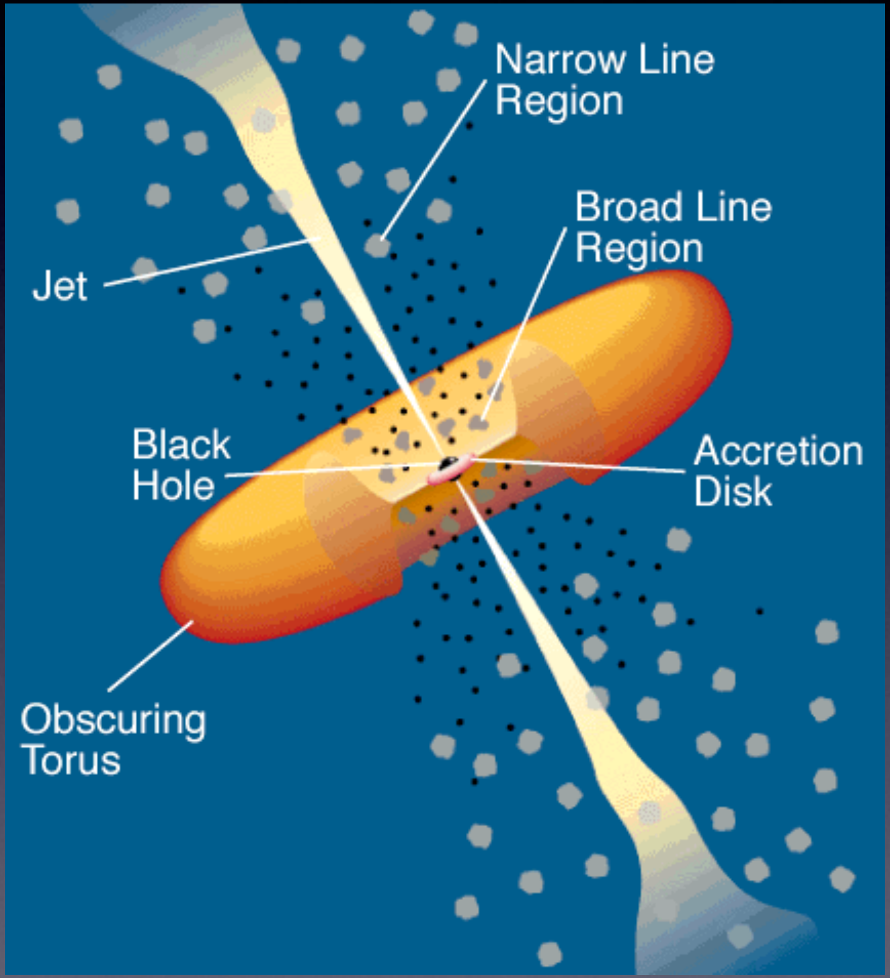
- M_{BH} vs M_{Bulge} relationship
- Avoidance of over-production of massive galaxies
- “Old, red and dead” ellipticals

Recurrent radio-loud AGN activity is thought to be a strong driver of the “quenching” of massive gals. But:

- What type of radio-AGN?
- How is the feedback triggered?
- How does it evolve with redshift?



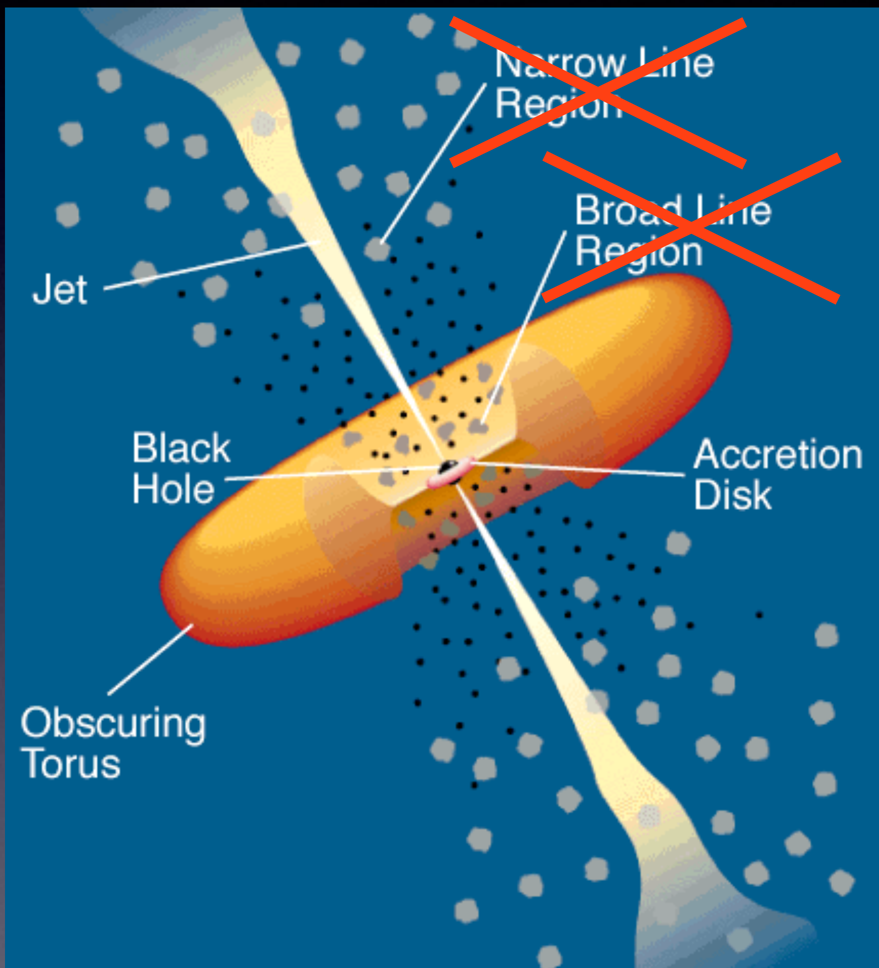
"Standard" AGN activity



"Radiative/Quasar-mode" AGN:

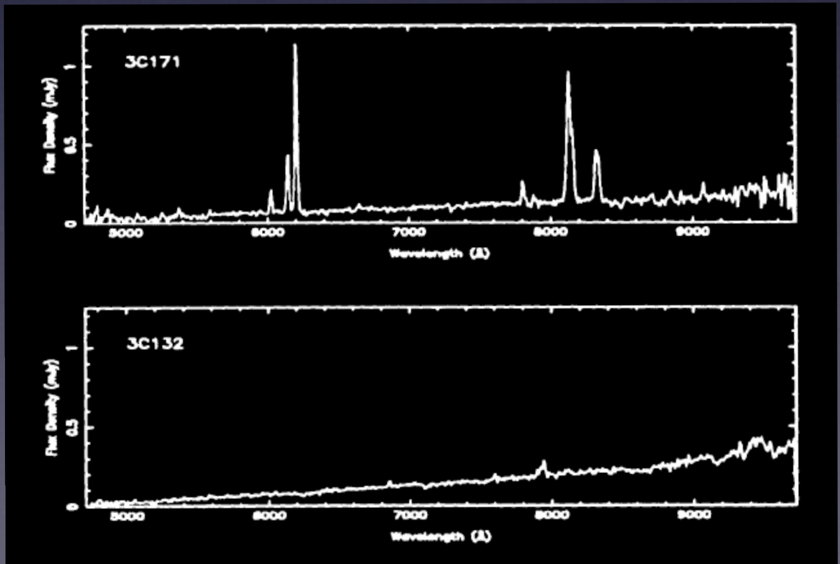
- Luminous accretion disk
  - optically thick
  - geometrically thin
  - associated X-ray corona
- Bright line emission
  - UV ionising radiation from disk
- Dusty obscuring structure
  - emits in IR/sub-mm
- Orientation-dependent observed properties
  - Type 1 vs Type 2 AGN
- Sometimes, extended radio jets

Another class of AGN



Other AGN, exemplified by weak radio sources, don't fit this scheme:

- No strong emission lines
  - (Hine & Longair 1979)



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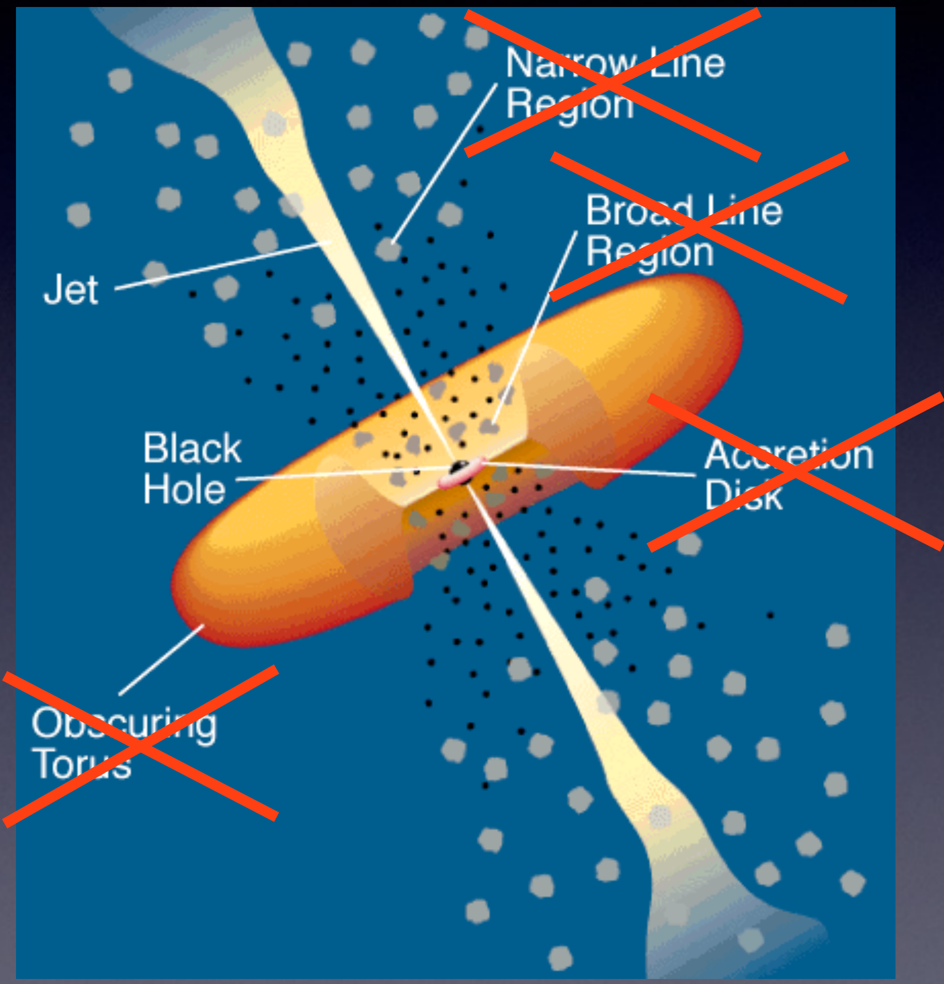

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- No accretion-related X-ray emission

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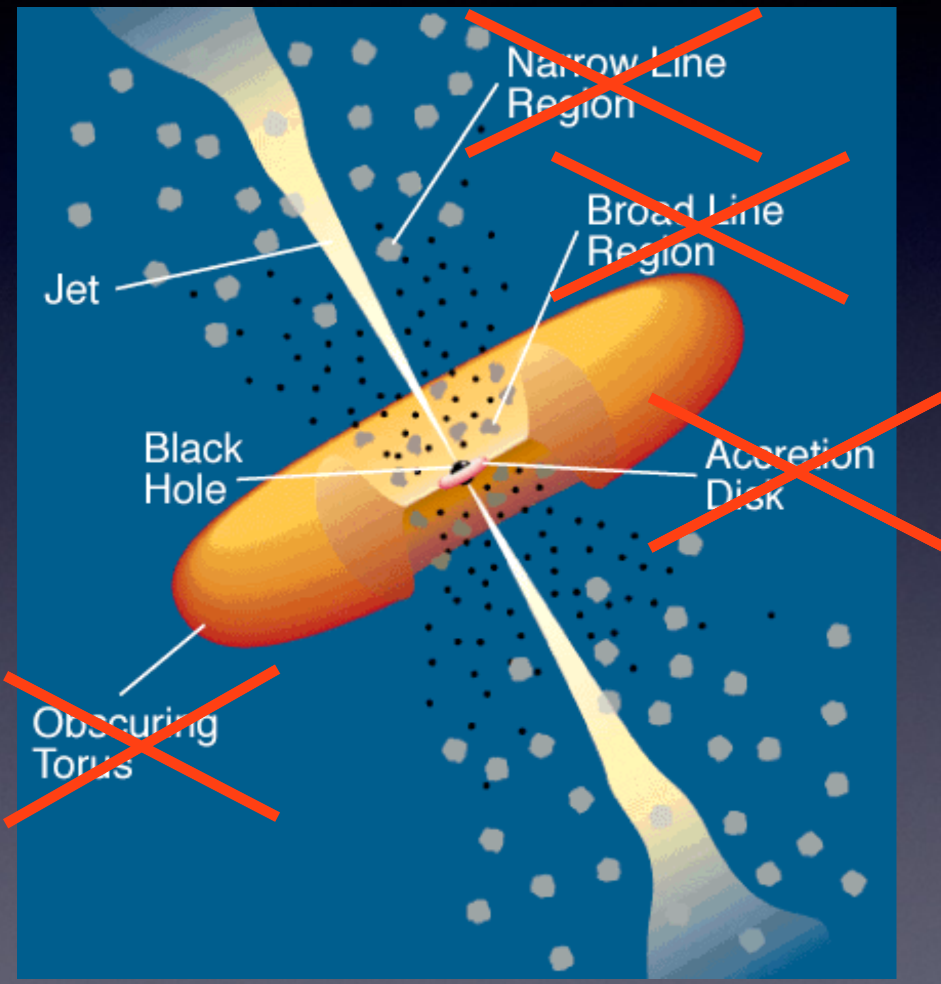


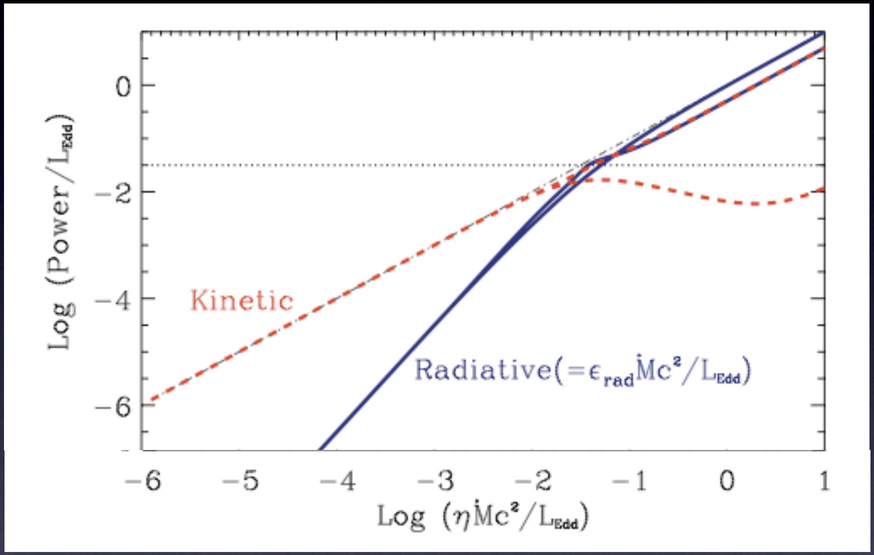
Other AGN, exemplified by weak radio sources, don't fit this scheme:

- No strong emission lines
  - (Hine & Longair 1979)
- No IR emission from torus
- No accretion-related X-ray emission
- Only strong evidence of AGN activity is the jet…

Why different AGN?

Accretion flow modelling (e.g. Narayan & Yi 1994,5) predicts a change in the nature of accretion flows at low fractions of Eddington:

- high accretion: optically thick, geometrically thin disk; strong radiative emission, sometimes also with jets
- low accretion: radiative-inefficient advection-dominated accretion flow (ADAF/RIAF): most energy comes out as jets - ‘jet-mode’ AGN
- accretion mode switch is observed in micro-quasars, at about 1% Edd.

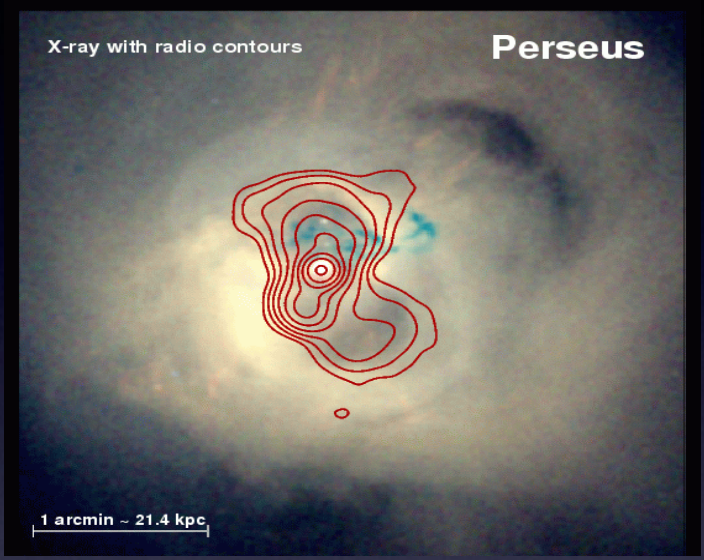


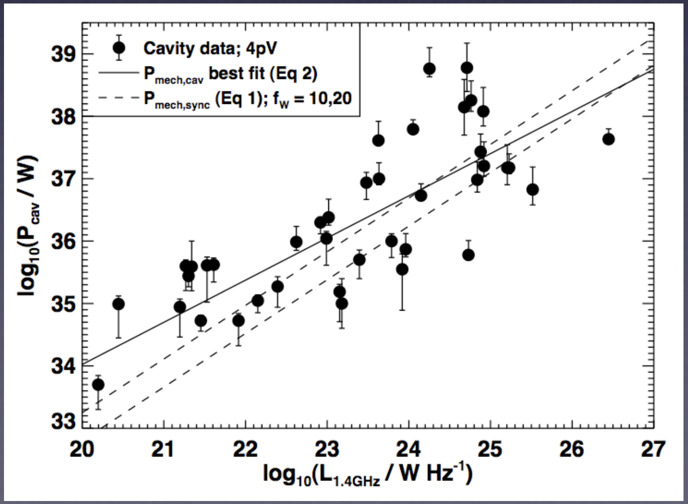
Schematic of the switch between kinetic AGN output for accretion rates at low fractions of Eddington, and radiative output at high fractions (Merloni & Heinz 2008)

Testing accretion mode picture

Best & Heckman 2012, MNRAS, 421, 1569

- Cross-match SDSS DR7 with radio catalogues: ~18,000 sources
- Classify as radiative-mode (high-excitation) or jet-mode (low-excit.)
  - using SDSS emission line ratios
- Calculate Eddington fraction, f_{Edd}:
- $f_{Edd} = L/L_{Edd} = (L_{rad} + L_{mech}) / L_{Edd}$
  - black hole mass from velocity disp.
  - radiative luminosity from [OIII] 5007 emission line luminosity
  - mechanical luminosity from radio luminosity (cavities/synchrotron)





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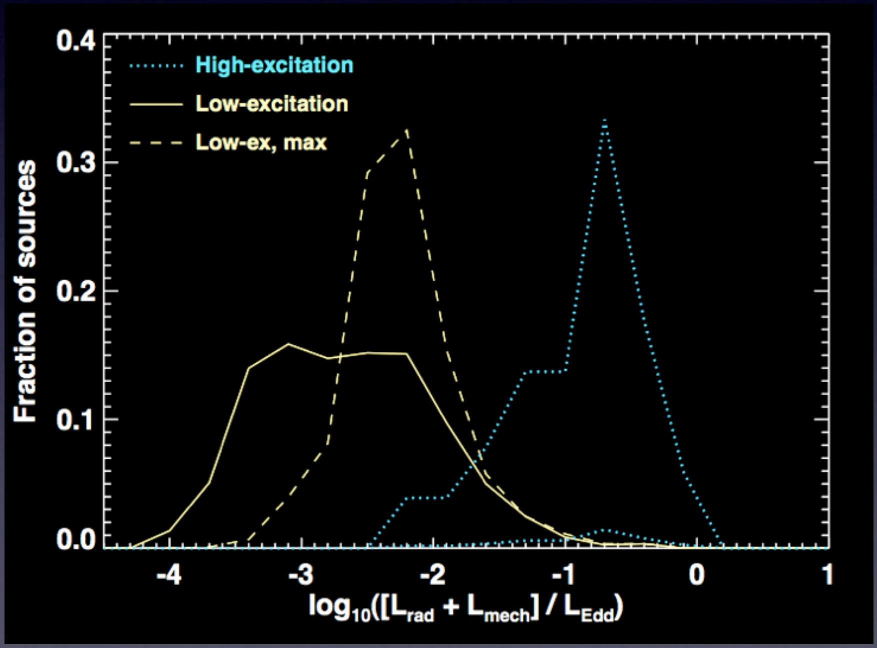
- Find clear dichotomy at ~1% Edd.



Jet-mode AGN energetics

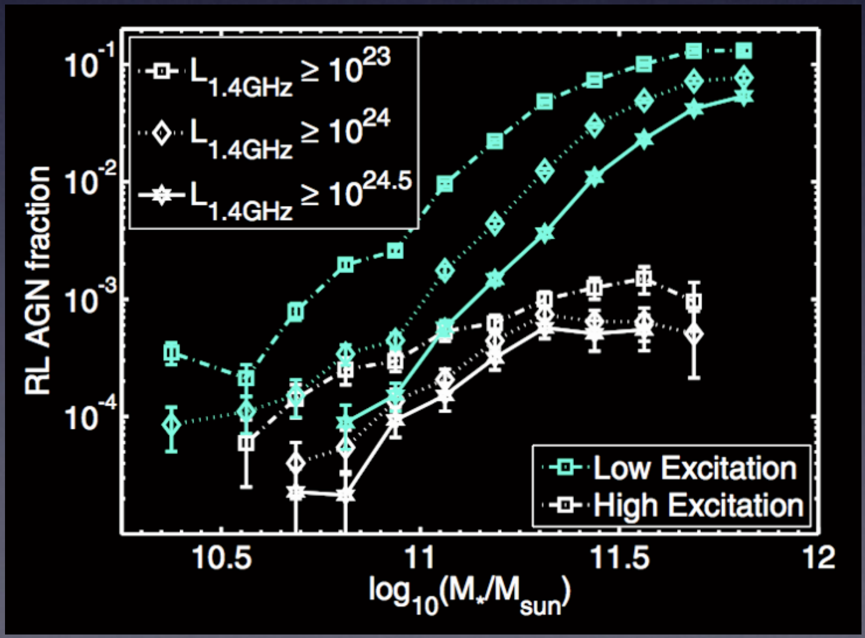
The fraction of galaxies that host jet-mode radio-AGN is a very strong function of galaxy mass

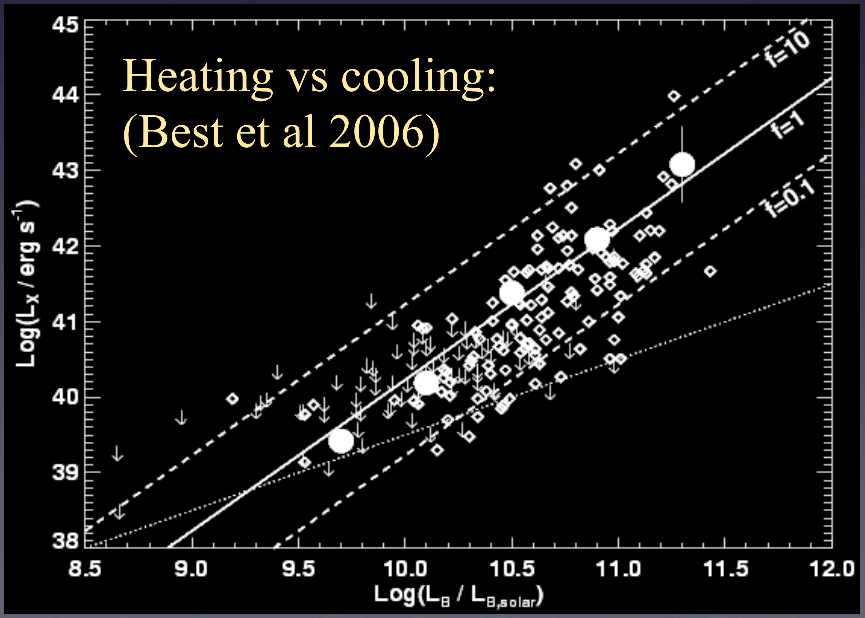
- these AGN are in ‘old,red,dead’ systems which need feedback
- hosted by central galaxies, generally not satellites

Their low accretion rates can be supplied by gas cooling from hot halo

Evaluate time-averaged heating rate from recurrent jet-mode activity

- closely balances cooling losses from surrounding hot gas halo





A radio-AGN feedback cycle

Hot gas emits in X-rays and cools.
(faster in more massive systems)

Cooling rate increases; some gas falls onto the central black hole

Radio-AGN switched on. Jets deposit energy into surrounding gas

Hot X-ray gas is heated by AGN; gas cooling stops

No more fuel for black hole, so radio-AGN is switched off

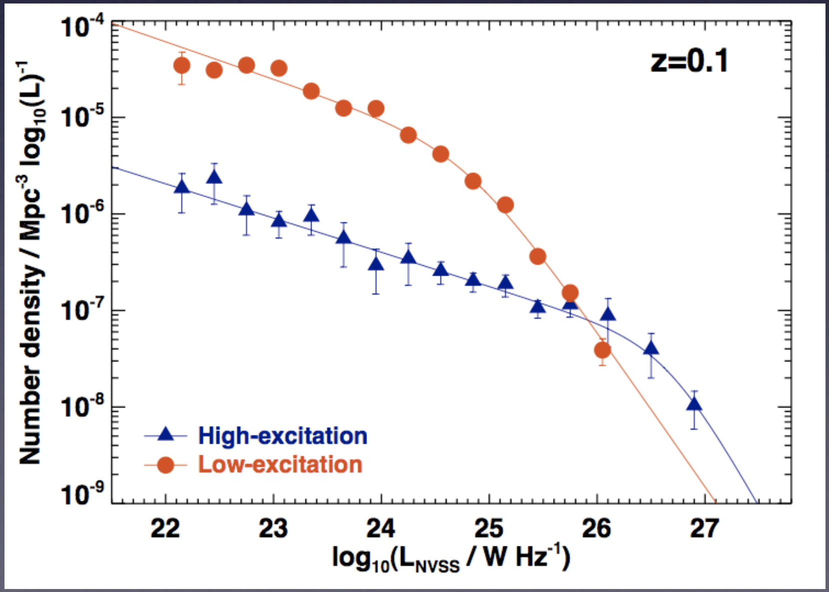
Radio-AGN act as a "cosmic thermostat" controlling the cooling of the hot gas. Maintains host galaxy as "old, red and dead"

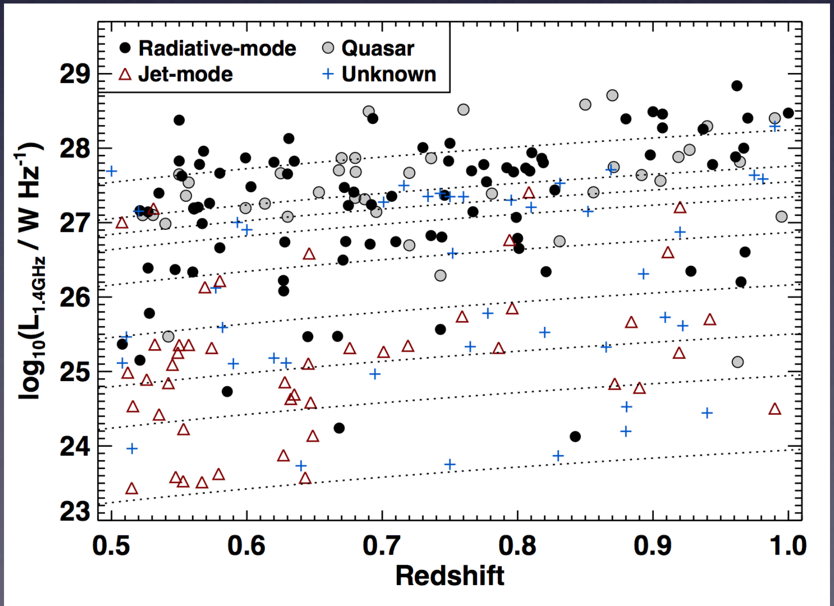
Cosmic evolution of radio-AGN

Best et al 2014, MNRAS in press, arXiv

To determine the evolving importance of radio-AGN feedback we need to measure cosmic evolution of jet-mode AGN

- Combined 8 radio source samples at 0.5<z<1.0, to build a >200 source sample with good radio luminosity coverage





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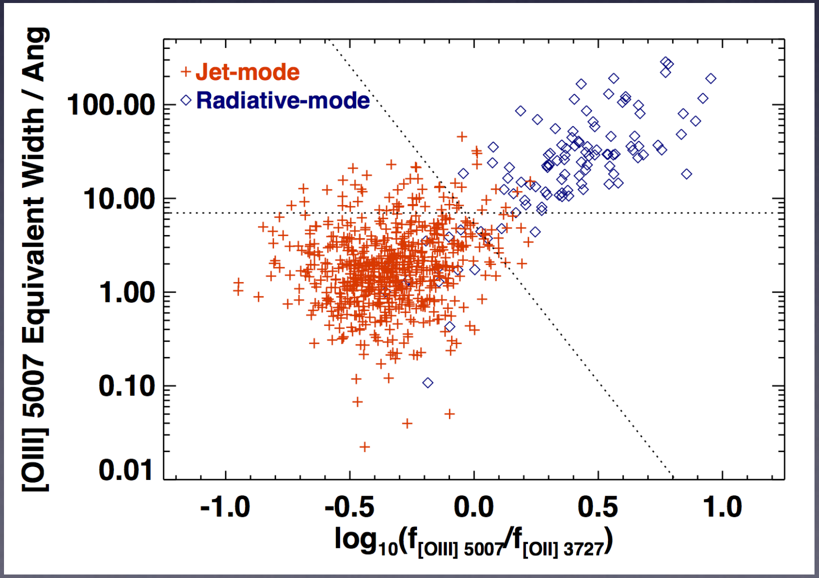
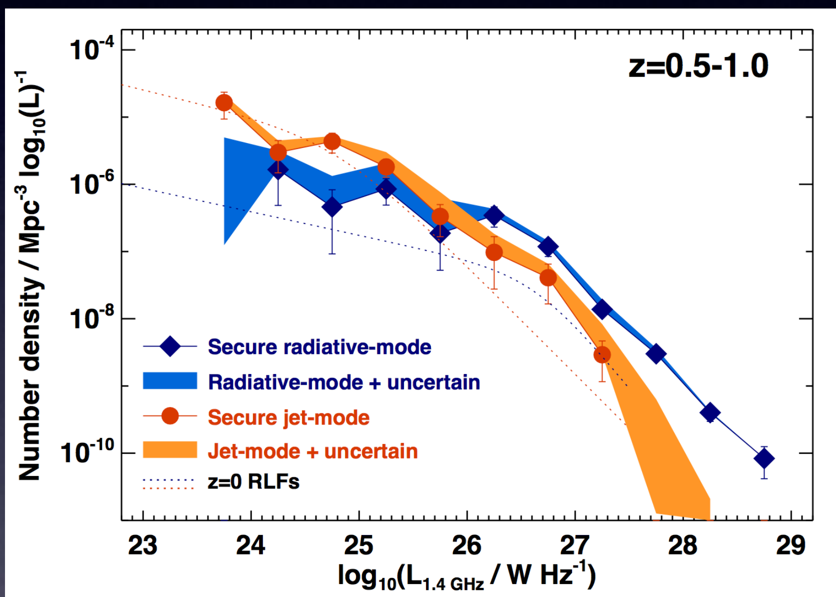
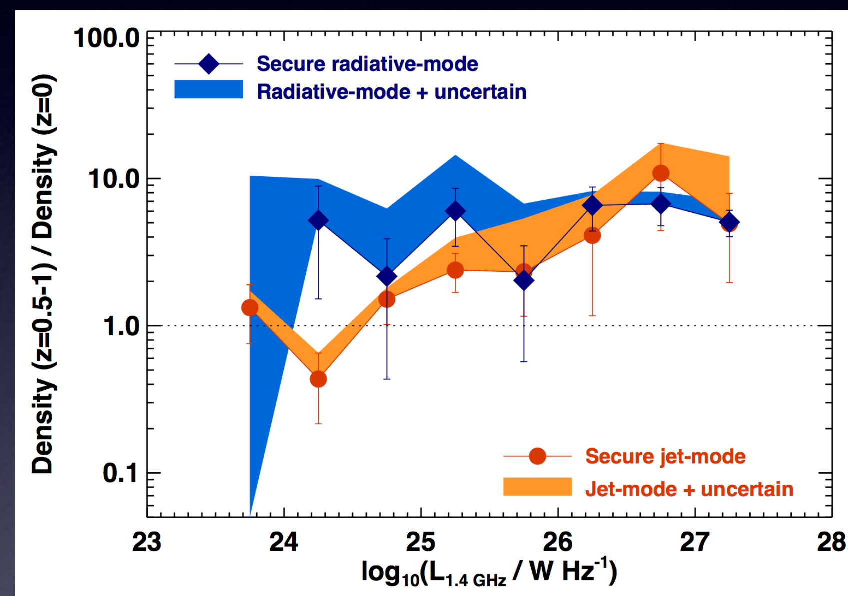
- Combined 8 radio source samples at 0.5<z<1.0, to build a >200 source sample with good radio luminosity coverage
- Spectroscopically classified using [OII] 3727 and [OIII] 5007 emission lines
  - used SDSS data to calibrate classification criteria



Cosmic evolution of radio-AGN

This has allowed us to derive the luminosity functions of the two separate populations, to compare with the local RLFs



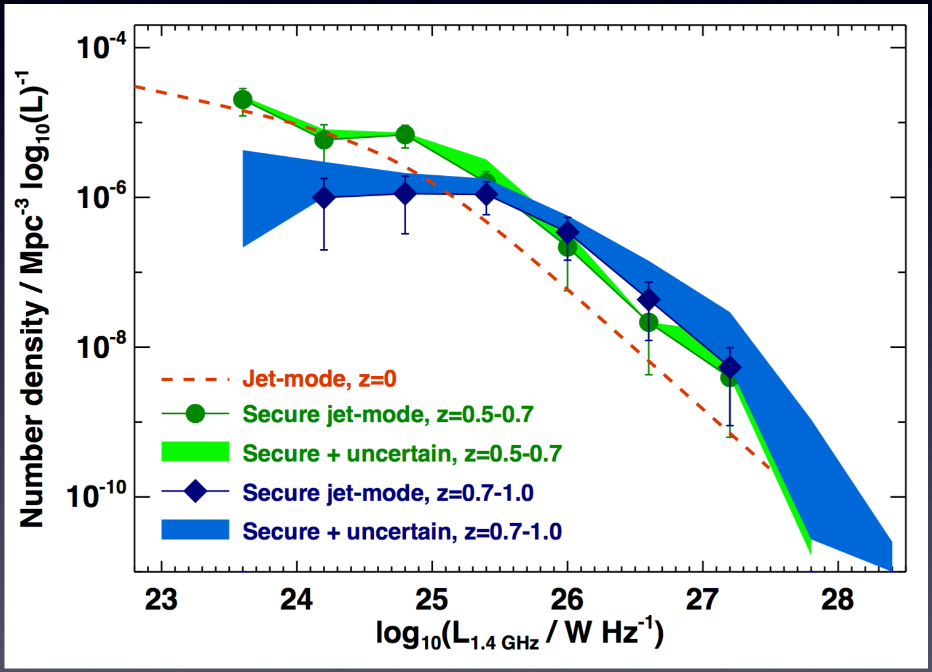


Radiative-mode radio-AGN evolve by factor ~7 at all luminosities

- consistent with picture that these are fuelled by cold gas

Jet-mode radio-AGN show no evolution at low luminosity, but evolve strongly at high luminosity

Evolution of jet-mode AGN



Can also split jet-mode AGN into two redshift ranges.

- At high luminosity, space density increases continually with redshift
- At low luminosity, space density of jet-mode AGN increases out to z=0.5, but then falls

Modelling the evolution

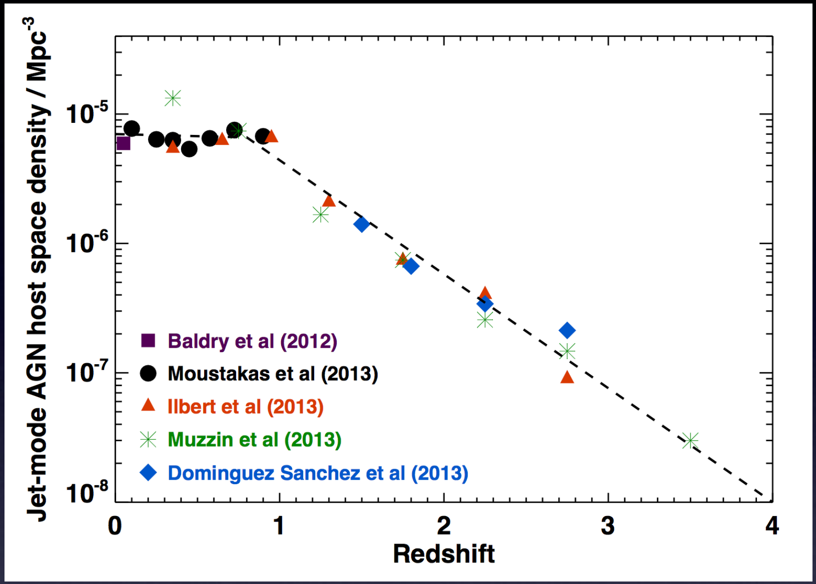
Simple model of jet-mode AGN:

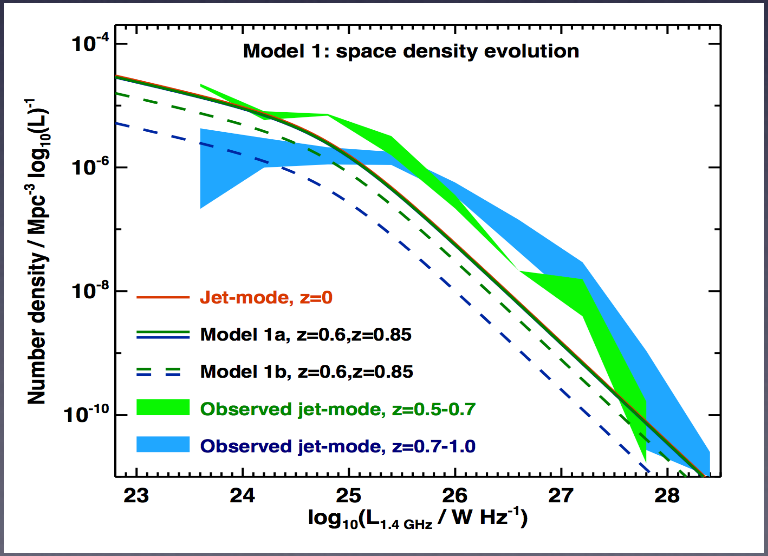
- quiescent massive galaxies
- fuelled by accretion of gas cooling from hot halos

We can therefore predict how the jet-mode RLF should evolve:

- Pure space density evolution, in line with space density evolution of potential massive host galaxies

“Model 1a”: doesn’t provide a good match to the data at high or low luminosity





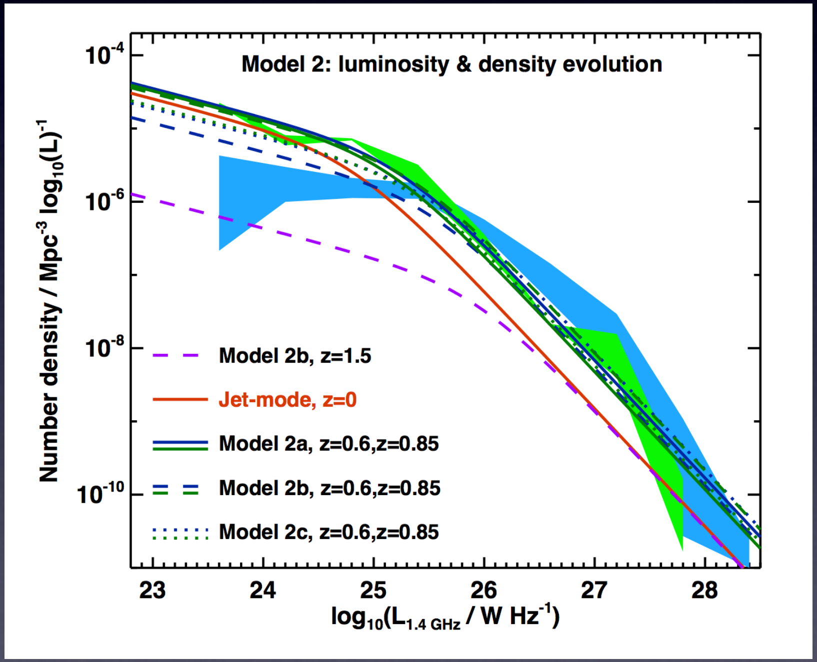
Luminosity-density evolution?

Universe is denser with higher gas fraction at high redshift

- radio sources more confined, and synchrotron emission boosted?
- luminosity + density evolution?

"Model 2a": good match at high luminosity, but still struggles to match low luminosity decline

- Note, if luminosity evolution does occur, it implies that the radio luminosity to mechanical jet power conversion is redshift dependent…



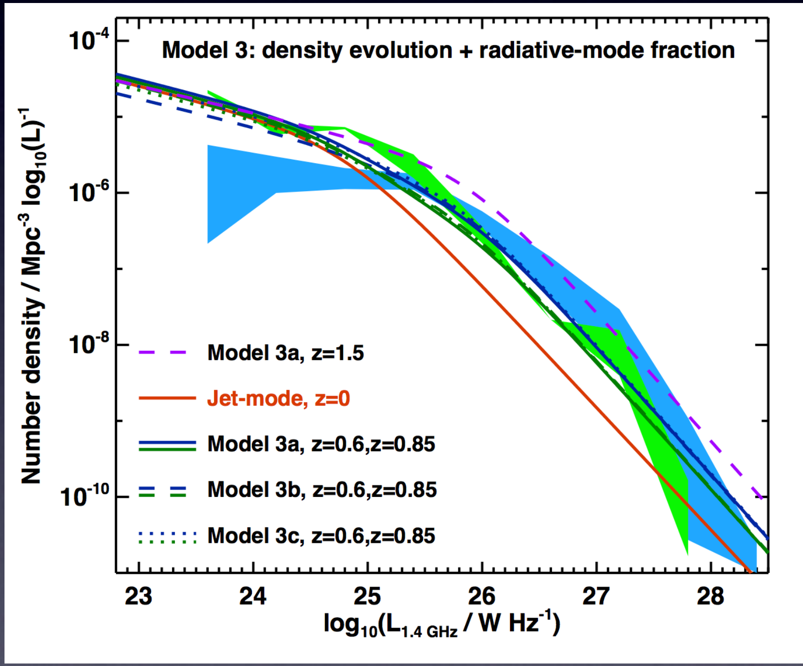
A cold-gas fuelled component?

Alternatively, “jet-mode AGN” include could a contribution of cold-gas fuelled sources:

- Hot halo gas fuelling always at low rates, leading to jet-mode AGN
- Cold gas fuelling usually at high rates leading to radiative-mode
- But cold gas could fuel at lower rates, producing jet-mode activity

“Model 3a”: allows radiative-mode fraction scaled in L and rho. Also good match at high luminosity

- Direct test of accretion theory



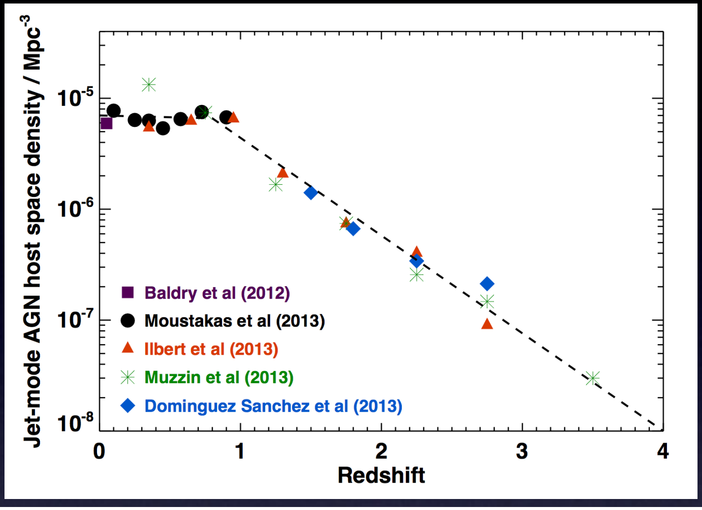
A delay before jet-mode activity?

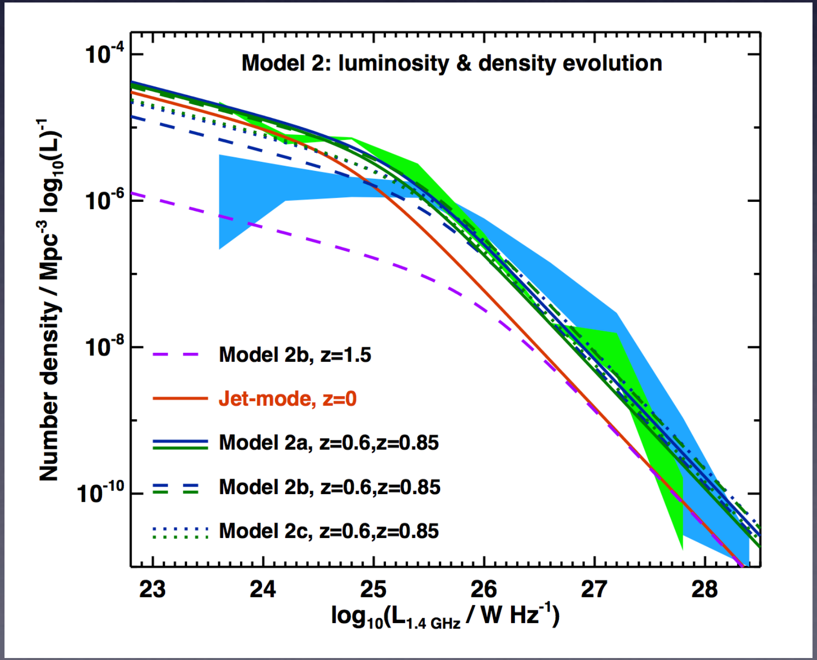
Is there a delay between galaxies becoming quiescent, and jet-mode radio-AGN activity starting up?

- might help explain why radio-AGN hosts are always amongst largest quiescent galaxies at their epoch

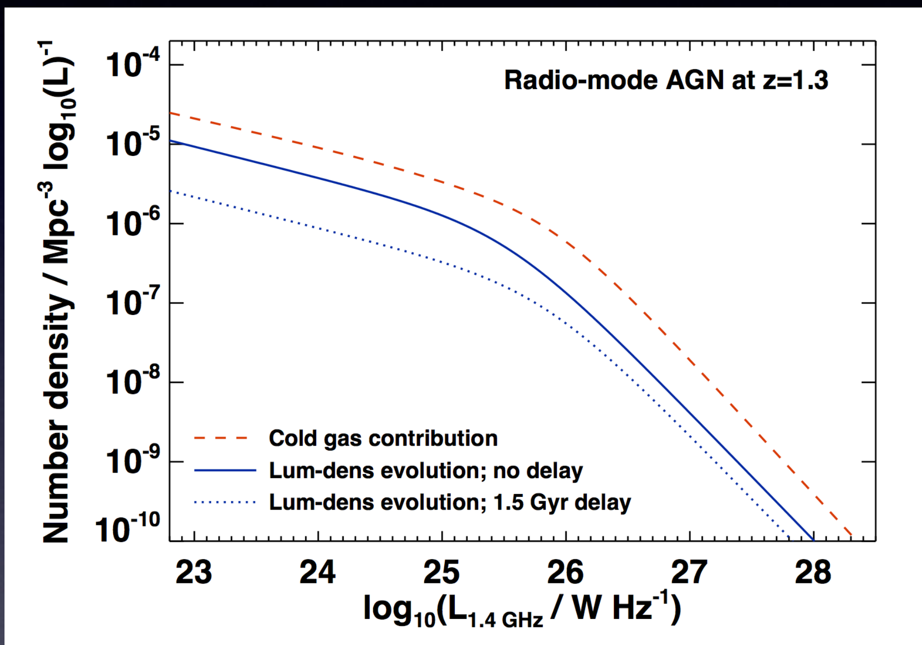
"Model 2b": acceptable match to the data at all lums, with 1.5Gyr delay

- If this delay is real, it would imply that jet-mode AGN activity is not responsible for the quenching process, only for "maintenance" of quenched galaxies





Which model is correct?



Three different models, each with important implications.

None can be statistically excluded using current data at $0.5 < z < 1.0$.

Best way to distinguish comes from higher redshifts:

- predictions for space density are very different by z=1.3

Summary

- Not all AGN follow the "standard" accretion disk picture
  - population of low accretion rate, radiatively inefficient, radio sources, dominates the low-luminosity end of RLF
- These sources are in massive galaxies, and appear to be fuelled directly or indirectly from the hot gas halo
  - radio source activity is highly-recurrent
  - time-averaged energetic output balances cooling rates of hot halo gas, leading to a radio-AGN feedback cycle.
- Jet-mode AGN show cosmic evolution broadly in line with expectation from evolution of massive galaxy hosts but:
  - also need luminosity evolution (L_{rad}-L_{mech} must depend on z)
  - or need a contribution of cold-gas fuelled sources
  - + suggestion of delay between quenching & radio-AGN activity
- Higher redshift data will distinguish these possibilities