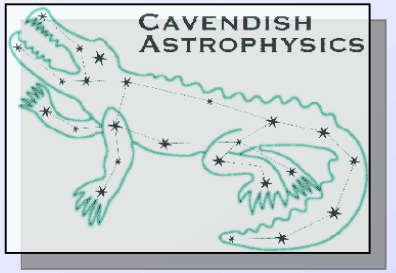
University of Cambridge
Department of Physics



Extragalactic Astrophysics and Cosmology in the Cavendish Astrophysics Group

Paul Alexander
Dave Green, Malcolm Longair,
Julia Riley, Martin Krause

Cavendish Astrophysics Group

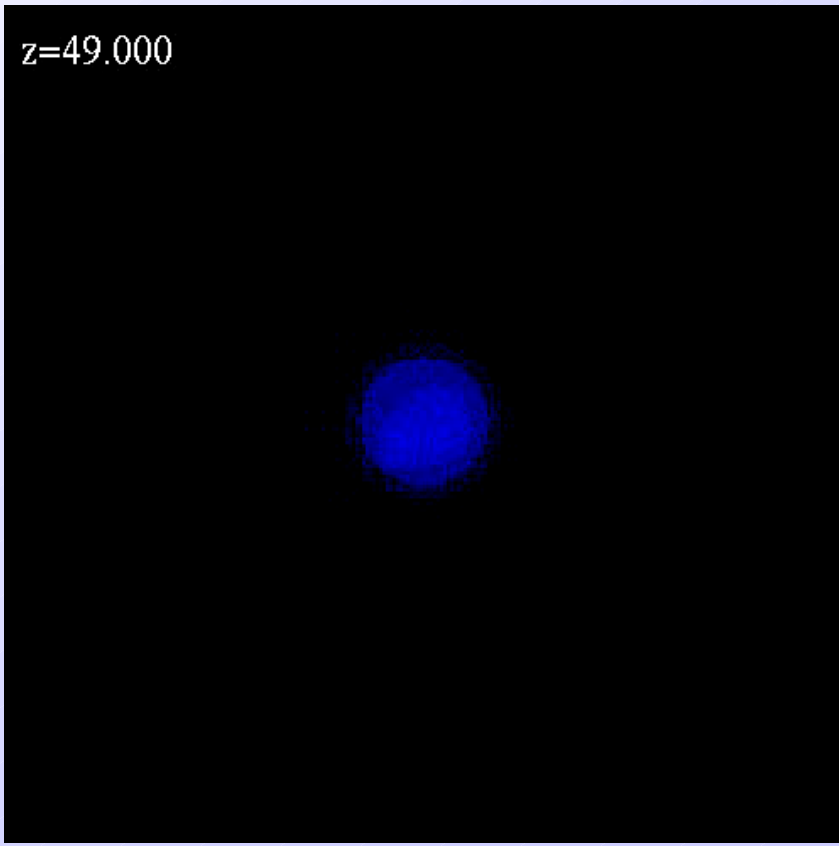
Large group with a background in experimental radio astronomy

13 Faculty

- **Cosmic Microwave Background**
- **Optical interferometry**
- **Extragalactic astrophysics and cosmology**
- **Star formation and the structure of the ISM**
- **ALMA**
- **Square Kilometre Array**

Feedback and Triggering in Galaxy Evolution

- **We currently have a good theoretical basis for studying galaxy formation and evolution based on the ΛCDM (Cold Dark Matter) Cosmological model**
- **Structure formation proceeds hierarchically with the continuing merger of dark matter halos**
  - **Baryoninc gas falls into the halos and is shock heated to the virial temperature and subsequently cools to form stellar systems**
- **Simplest models over predict numbers of faint and bright galaxies**
  - **Feedback is required**
  - **Need to study physical processes in detail to make further progress**



Feedback From Active Galactic Nuclei

- **Now clear that (all) galaxies host a black hole of mass proportional to the old stellar mass $E \sim \eta m_{BH} c^2$ → feedback**
- **But: how do we efficiently couple output of AGN to gas?**

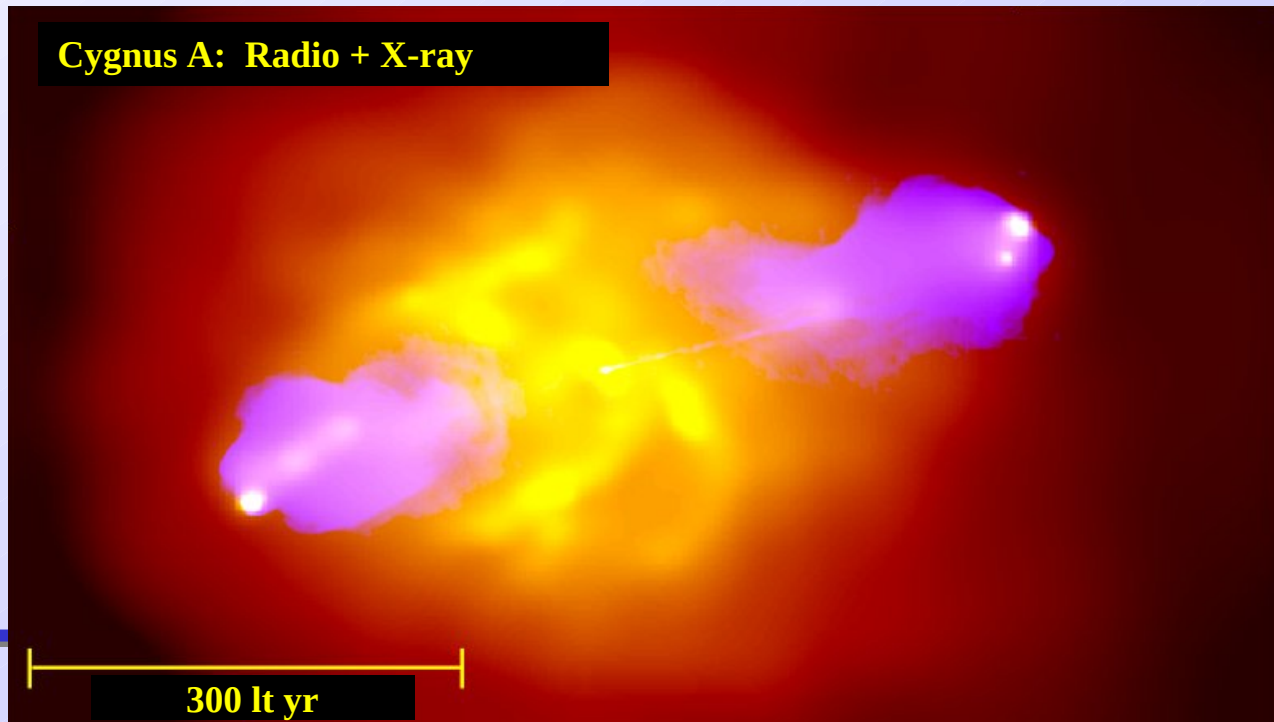
- **At least some AGN produce light, highly supersonic (relativistic?) jets → radio source**

- **Supersonic expansion**
  ⇒ heating by bow shock $\rho_j v_j^2 \sim \rho_x v_x^2$
  ⇒ gas swept up between bow shock and contact surface

- **Work done on external gas is *p*d*V* work**

  Stored energy in cocoon ~ *pV*

  ⇒ Heat deposited in external gas ~ *stored* energy



Effect of Radio Source on Its Environment

Energetically important:

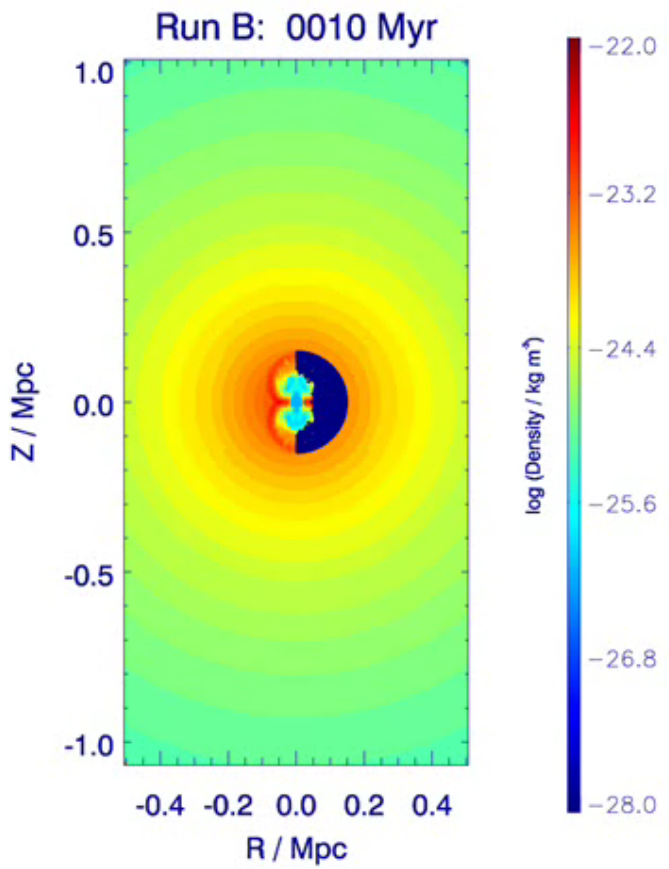
Jet powers $Q_0 \sim 10^{34} - 10^{40}$ W

Cooling rates $L_X \sim 10^{34} - 10^{37}$ W

But

Short $10^7 - 10^8$ yr timescale

Consider a relatively powerful Fanaroff and Riley Class II source

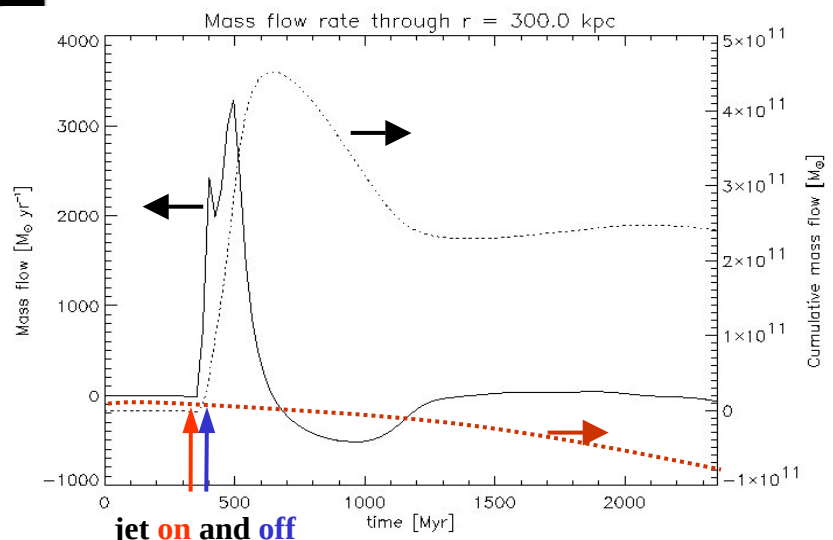


Cooling flow cluster **King profile**

$\beta = 0.5$ $T_{ICM} = 5\ 10^7$

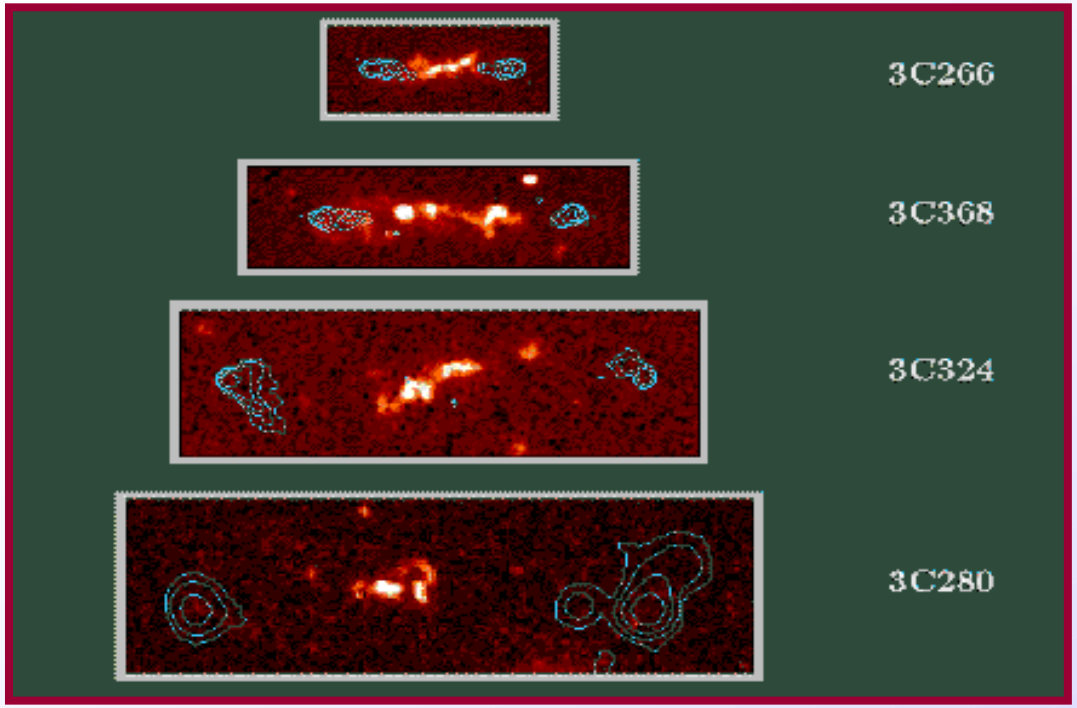
$n_0 = 1$ cm^{-3}; $M_j = 3.2$

$\rho_j/\rho_{ICM} = 0.001$



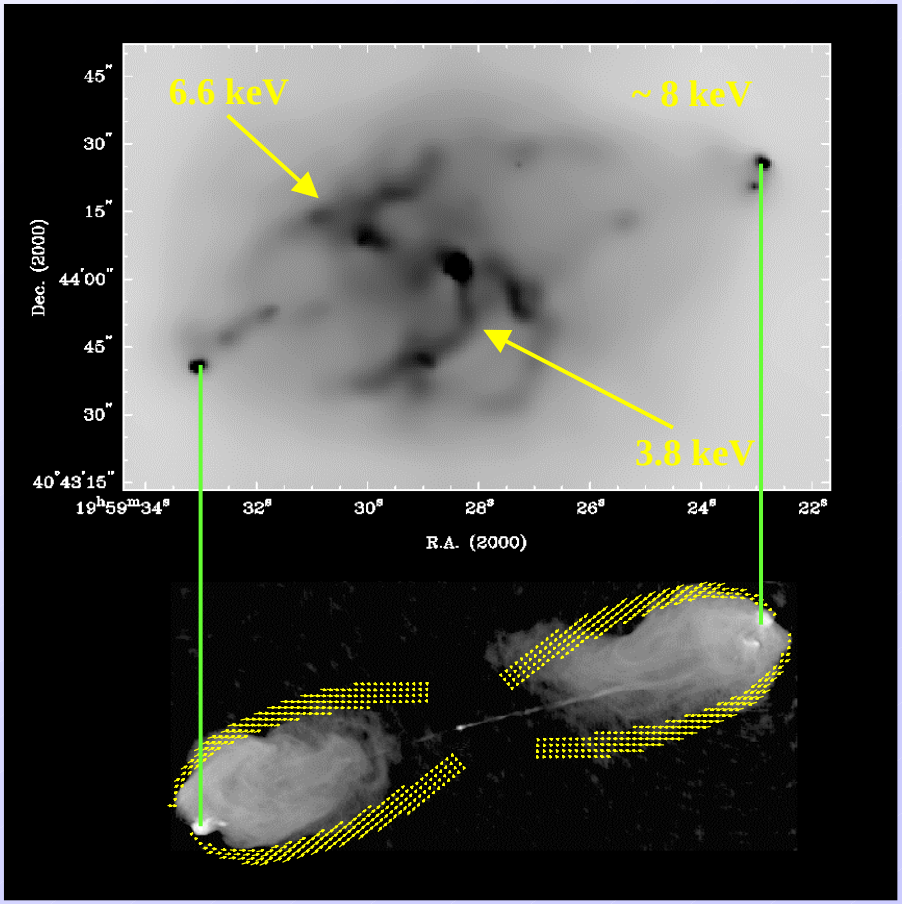
jet on and off

The Alignment Effect and Cloud Formation

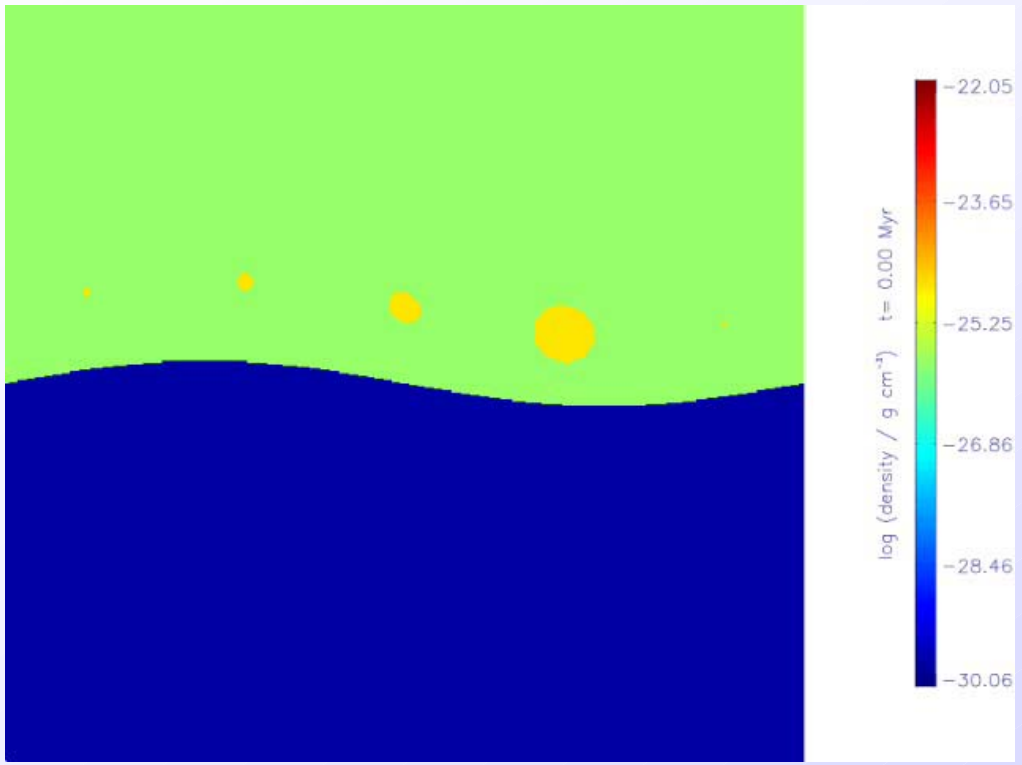


- Spatially extended continuum/line emission
  - ⇒ Filamentary structure, low filling factor
  - ⇒ Aligned along radio axis

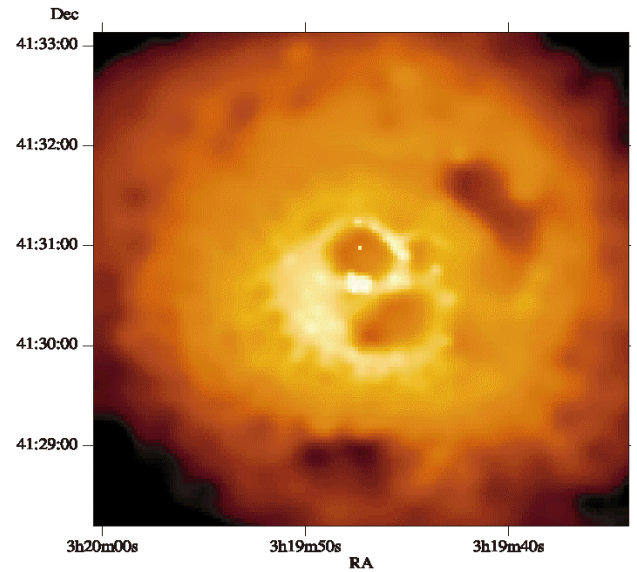
- Gas swept up by expanding radio source becomes unstable to a combined hydro dynamical / thermal instability

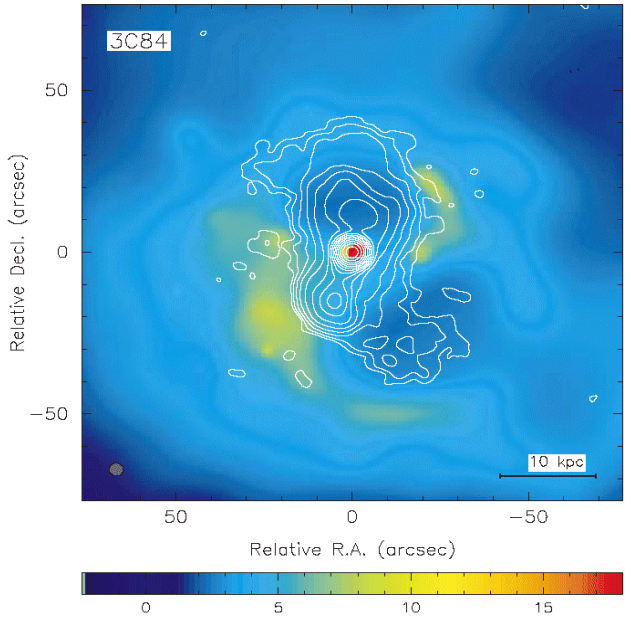


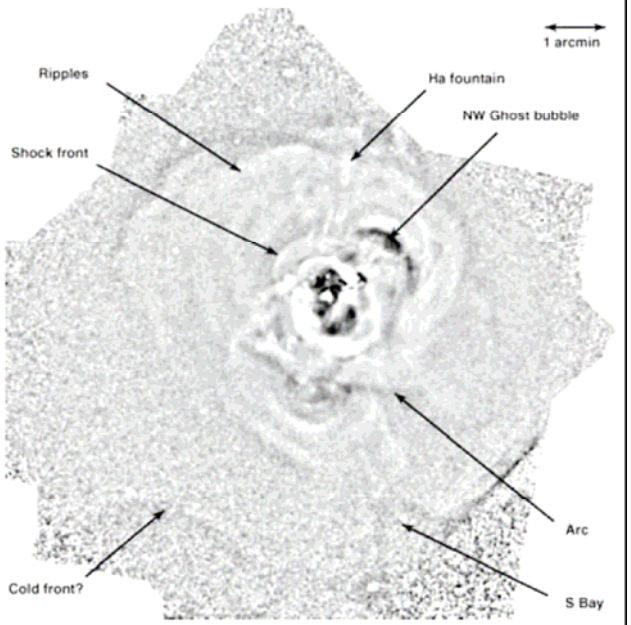
Cooling in a turbulent gas



Low-Power Radio AGN

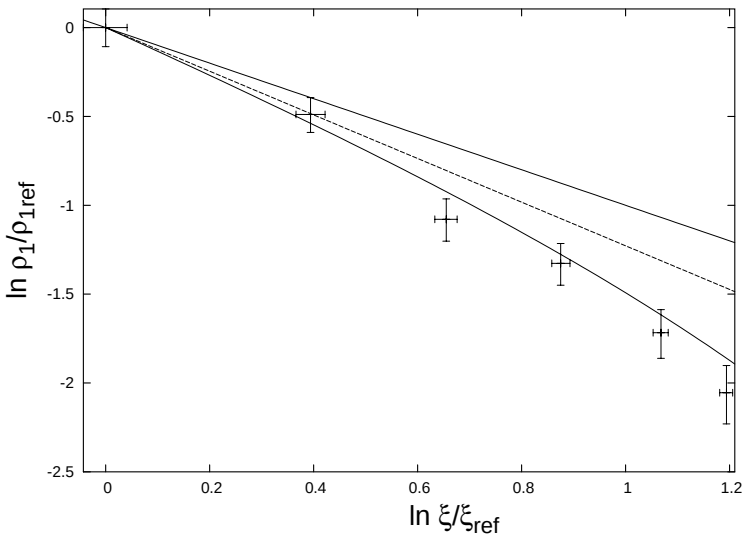






Fabian et al. 2000 and 2006

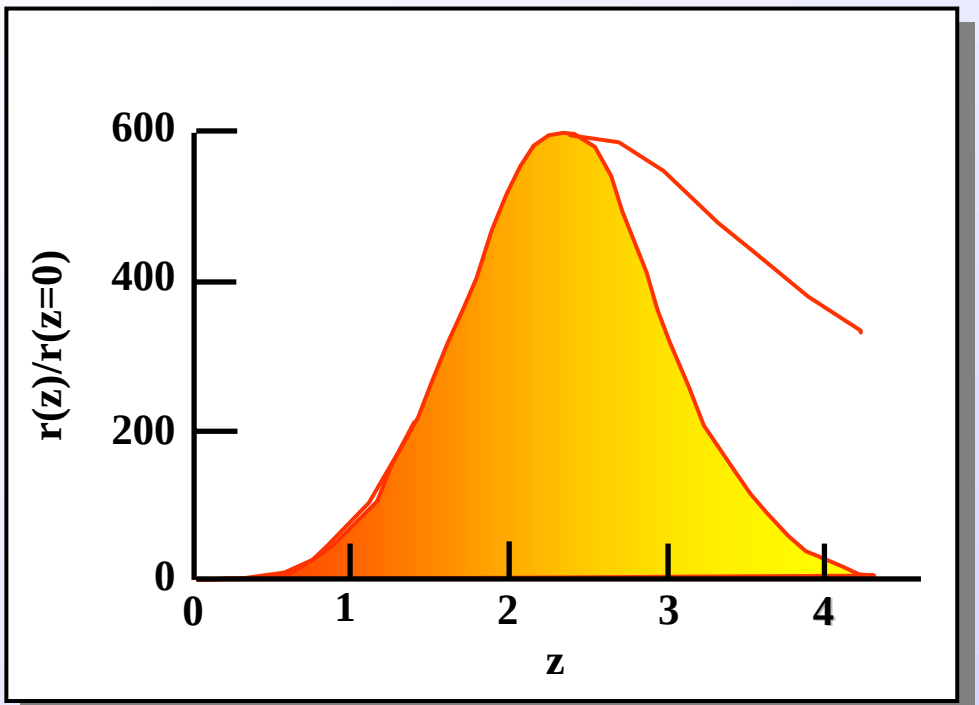
- **Adiabatic cooling of swept up gas forms a dense cool shell**
- **Natural oscillations of the cocoon generate sound waves which are very effective at heating ICM locally for many oscillatory periods**



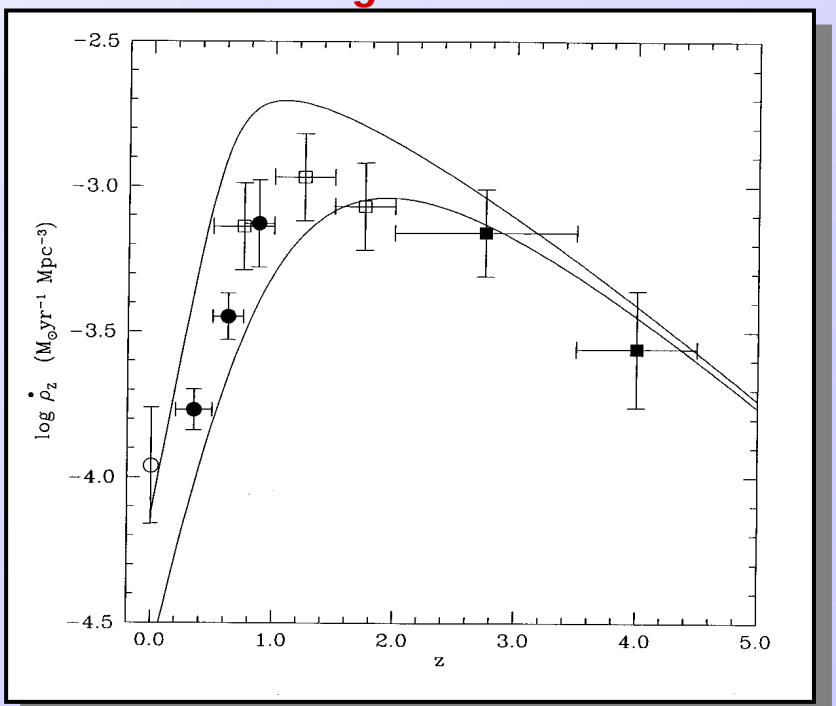
Triggering of “Activity”

- **Need to determine whether the AGN feedback is linked to the star formation process on both short and cosmological timescales and whether we can get efficient feedback**

Evolution of the radio galaxy and quasar populations



Rate of element formation / star formation in galaxies

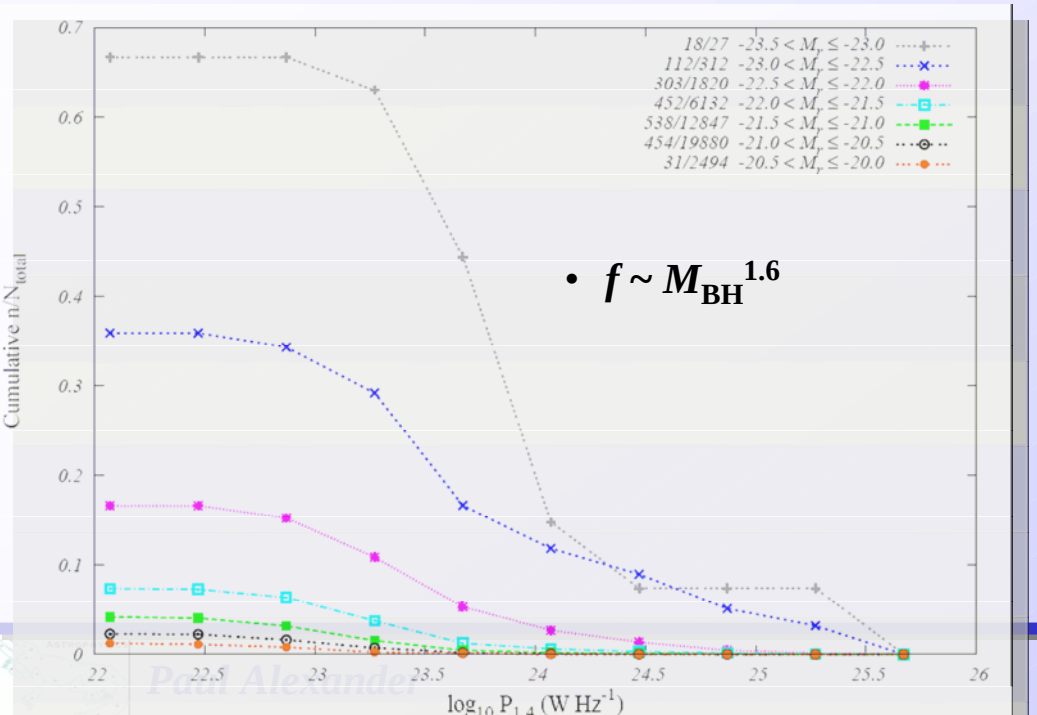


Triggering of "Activity"

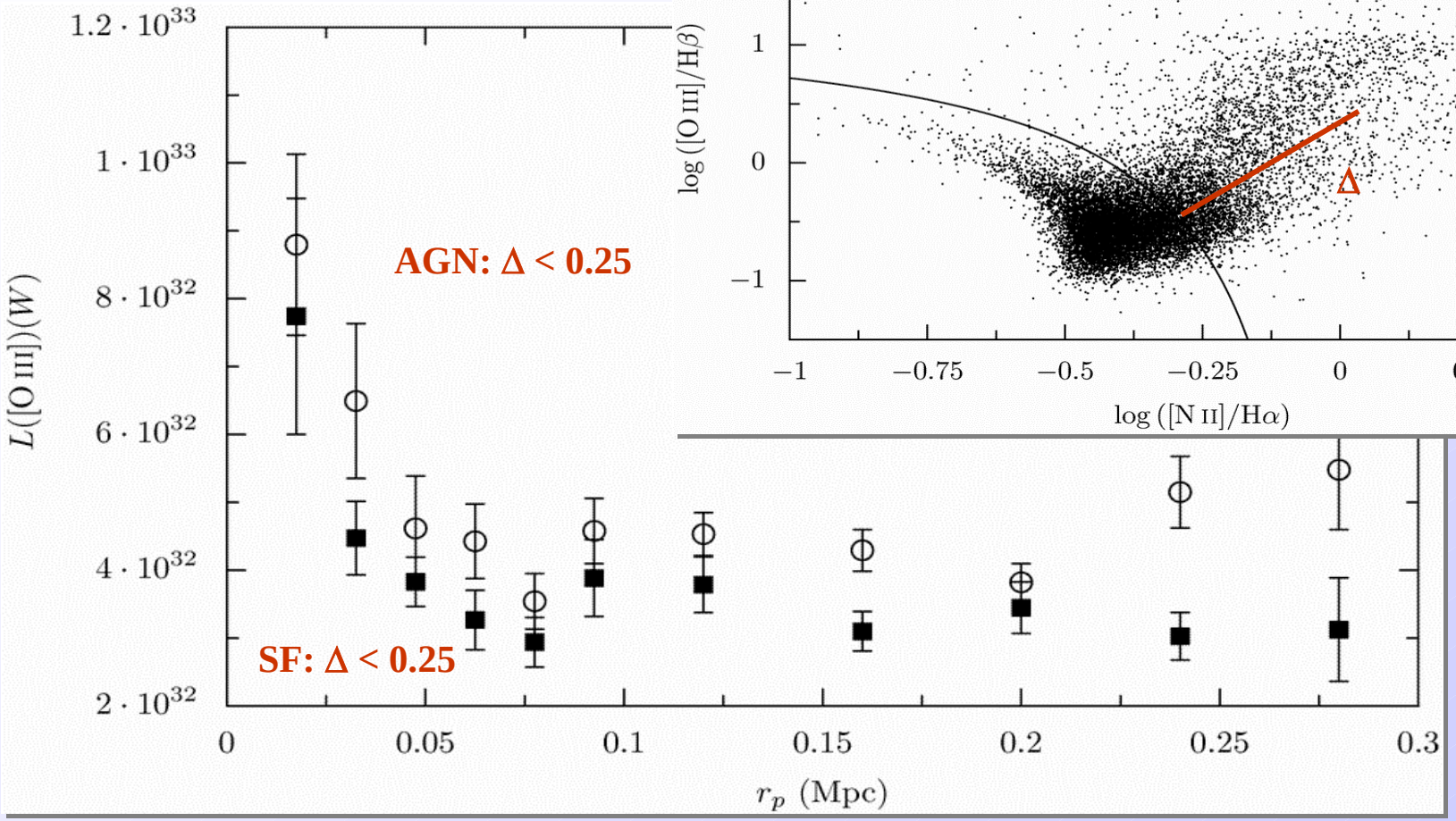
- **Volume and luminosity limited sample drawn from the SLOAN Main Galaxy Sample (MGS) 1360 sq degrees (area of DR1, data of DR2):**
  $0.03 < z < 0.1$ $M_r < -20.45$
  remove spurious detections: high redshift confidence & $m_z > 22.83$

- **38% AGN ~ 8600 objects**
  62% "normal" ~ 14000 objects

- **Find distance to nearest neighbour**

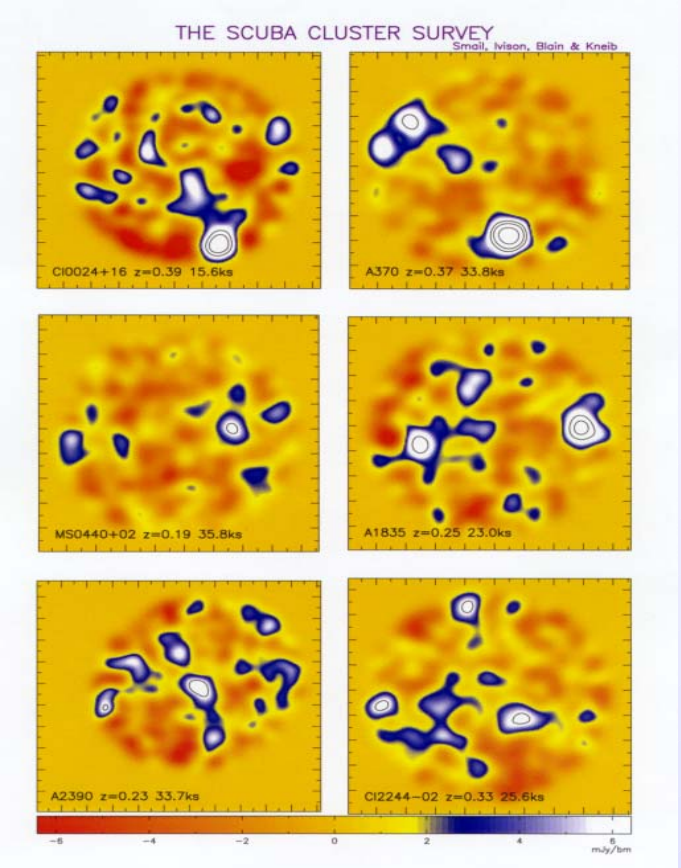


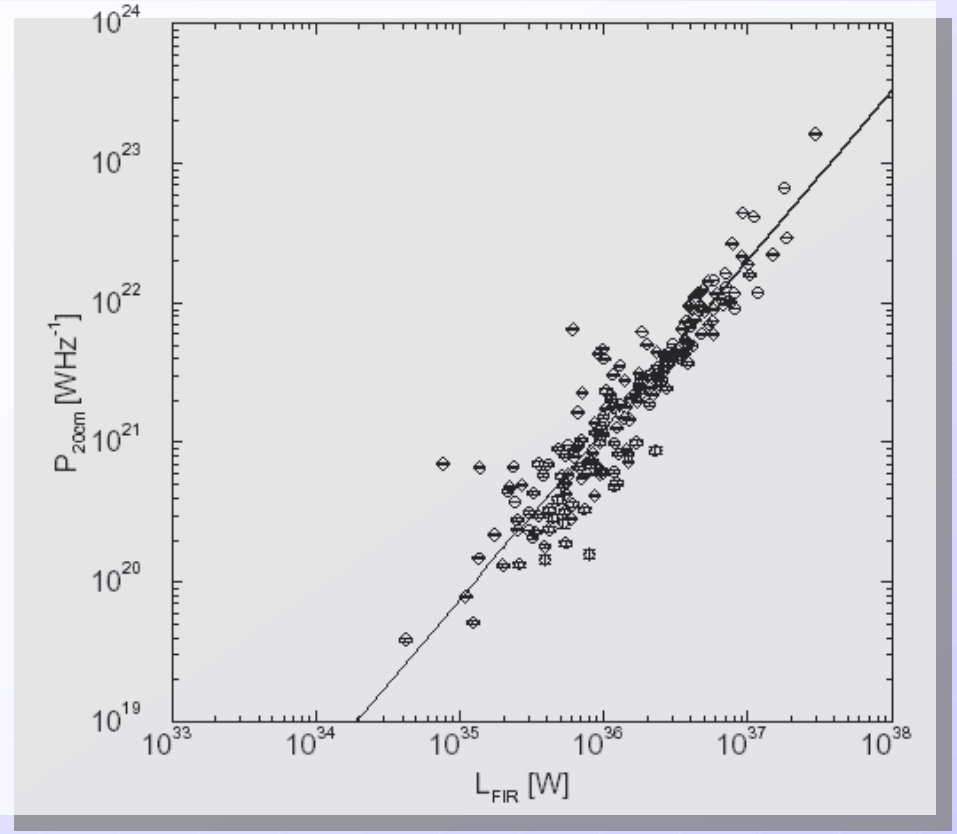
Tidal Triggered Activity in AGN



- **Tidally triggered enhanced [OIII] for both SF and AGN objects**
- **Tidally triggered SF is occurring in systems with an AGN**
- **Consistent with AGN activity being triggered at the same time or post starburst**

Activity at high redshift



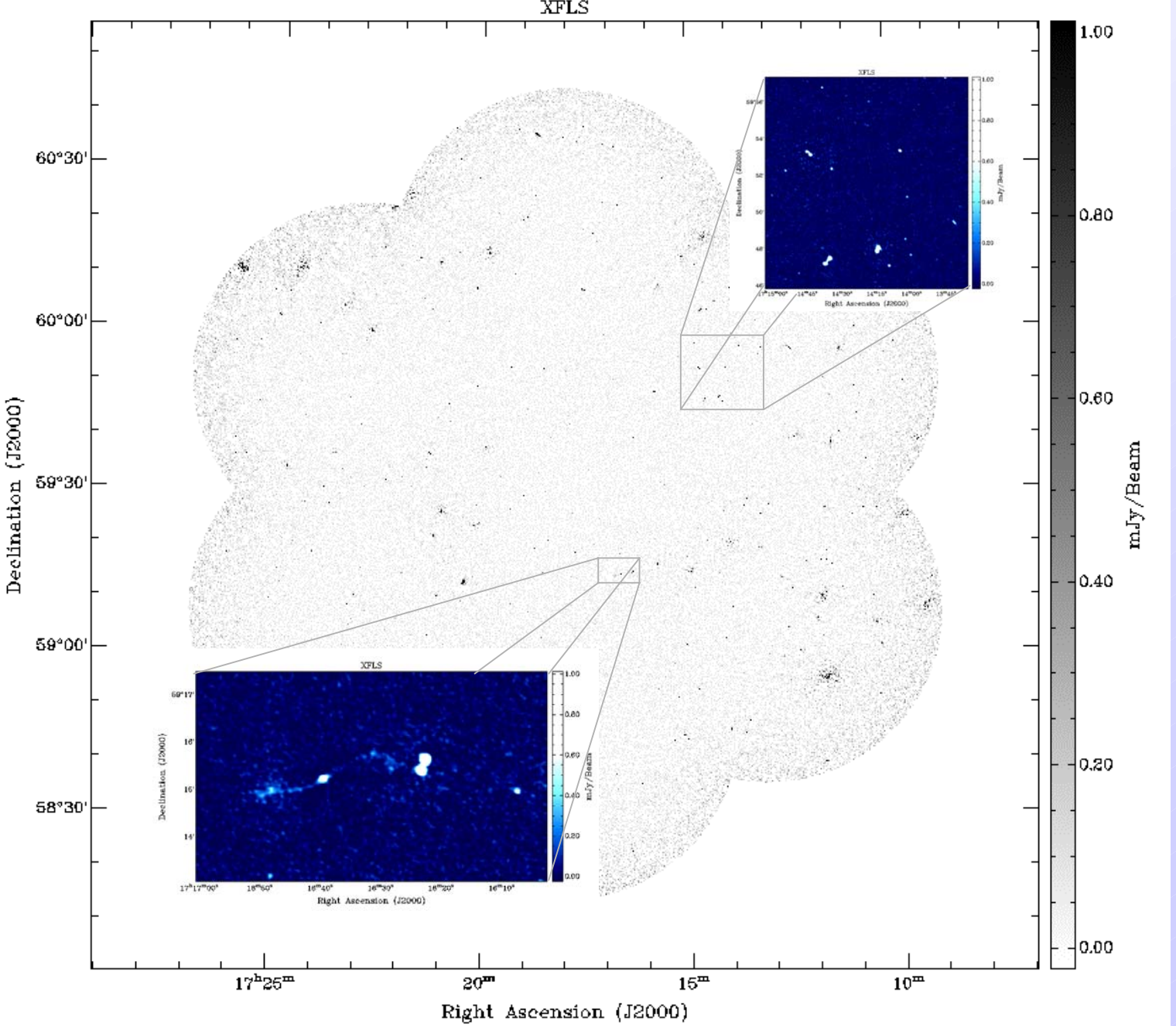


- **High redshift star forming / active galaxies highly obscured by dust – SCUBA on the JCMT**
- **Radio faint – need deep new data**

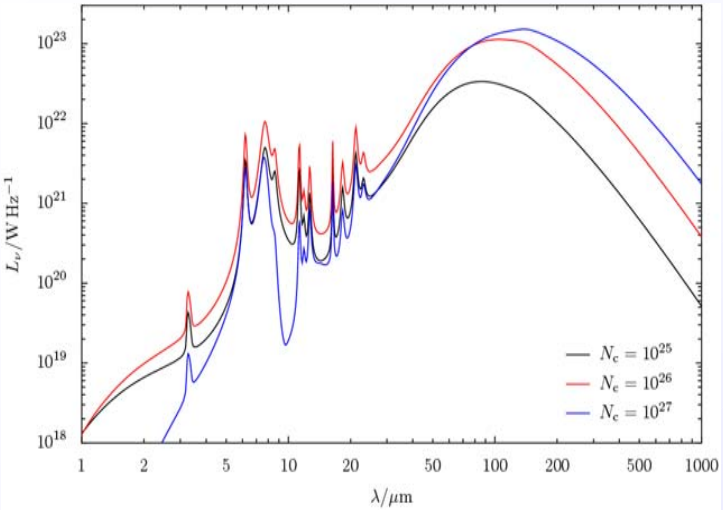
Radio Infrared correlation

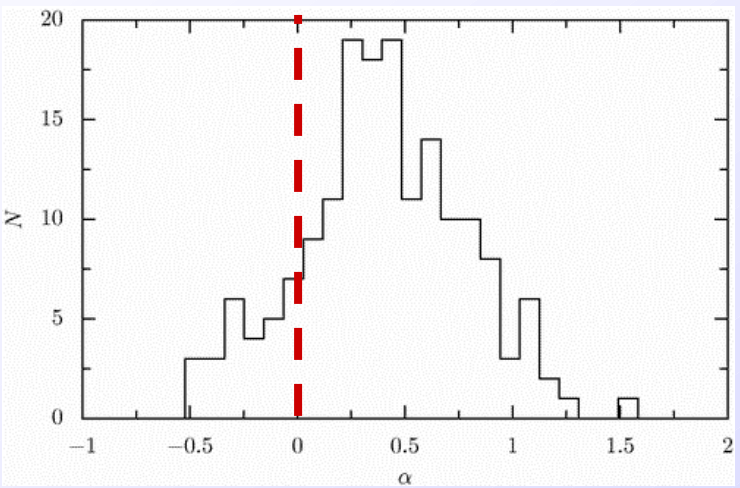
$$L_{50cm} \sim L_{20cm} \sim L_{70\mu m}^{1.1} \sim L_{24\mu m}^{1.1}$$

$$q = \log(L_{IR}/L_{radio})$$

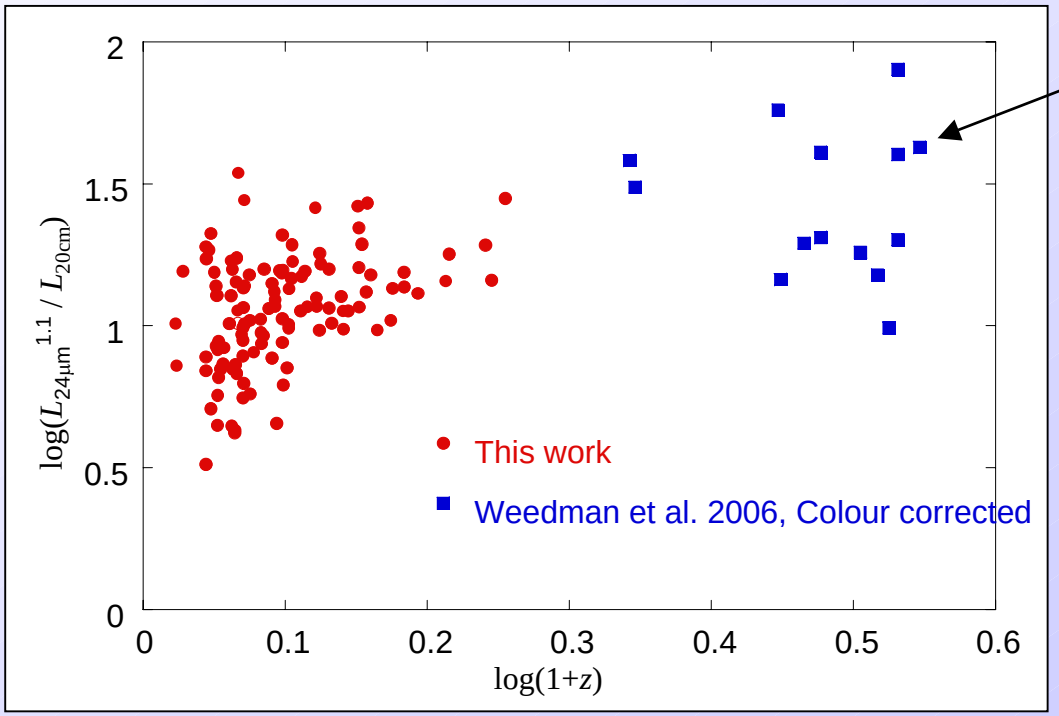

XFLS
60°30'
60°00'
59°30'
59°00'
58°30'
Declination (J2000)
17h25m
20m
15m
10m
Right Ascension (J2000)
1.00
0.80
0.60
0.40
0.20
0.00
mJy/Beam

IR-Radio Correlation at High Redshift





- **Carefully model IR and radio spectra to do K-corrections**



- **Correlation holds to high z**
- **Some (marginal) evidence for less radio emission at high redshift**
- ***B*-field in place at z=2.52, but may be less than now**

Some Future Directions

Origin of Magnetic Fields – SKA Key project

- **Model evolution of polarised sources**
- **Model / observations to place constraints on AGN being origin of seed field**

Can radio AGN solve the feedback problem

- **Timescales of Radio AGN activity**
- **Models of interaction and evolution**
- **Incorporate physics in cosmological model for galaxy evolution**
- **Incorporate effects of turbulence: gas striping, cooling etc.**

AGN Duty Cycle

- $f \sim M_{BH}^{1.6}$