Jet/environment interactions in FR-I and FR-II radio galaxies

Judith Croston

with

Martin Hardcastle, Mark Birkinshaw and Diana Worrall

University of BRISTOL

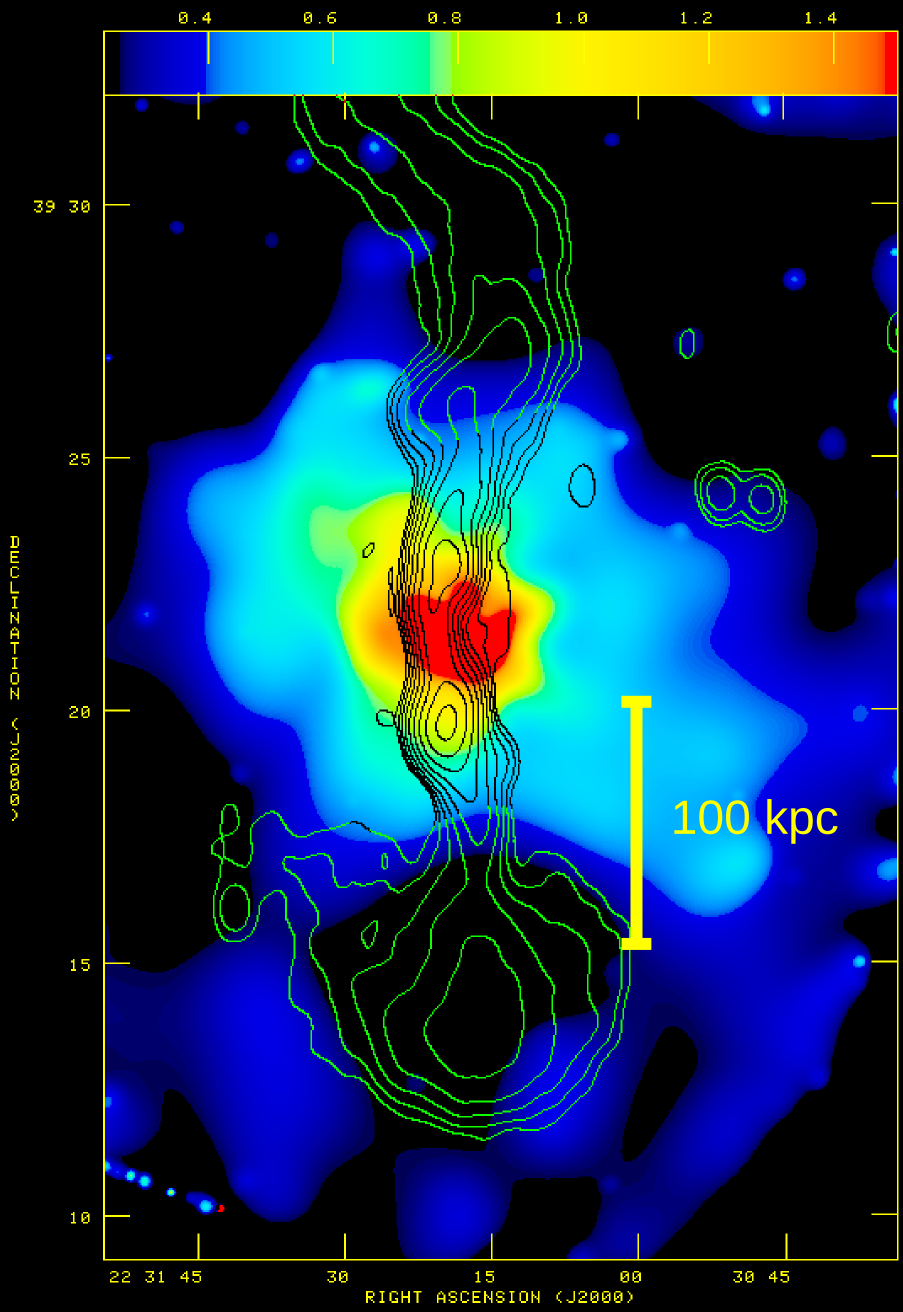
Outline

- Interactions in FR-Is
  - how is the radio structure affected?
- Interactions in FR-IIs
  - what is the content of the radio lobes?
- Radio-source heating of groups
  - how are environments affected?

1. Interactions in FR-Is

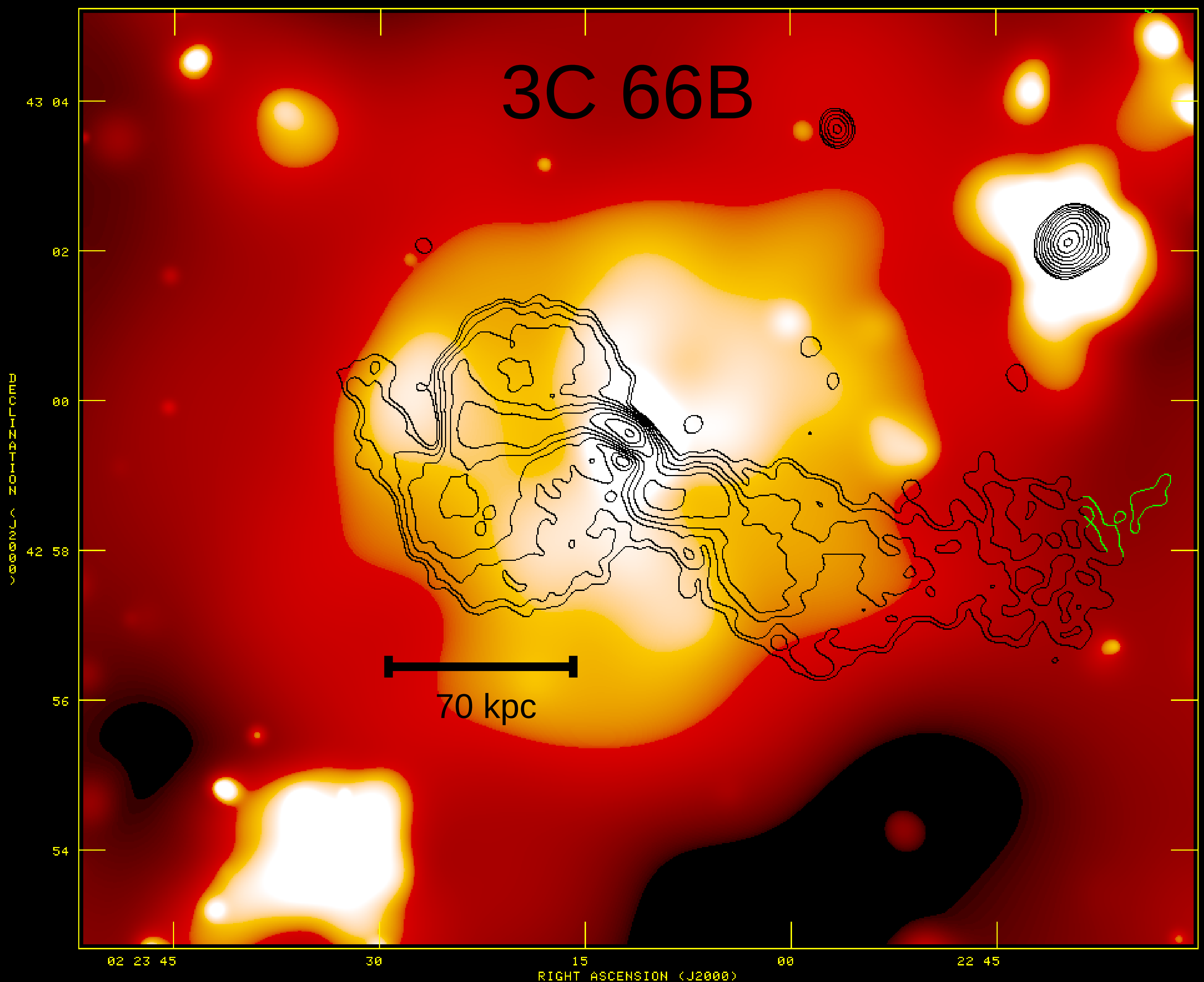
- Wide variety of lobe morphologies; in what circumstances do they form?
- Lobes transfer energy by doing work on the surrounding gas.
- "Cooling-flow" clusters nearly all contain an FR-I: can they solve the cooling-flow problem?
- Thought to expand subsonically, so that energy transfer would not be via strong shocks

  (but cf. Cen A, Kraft et al.)



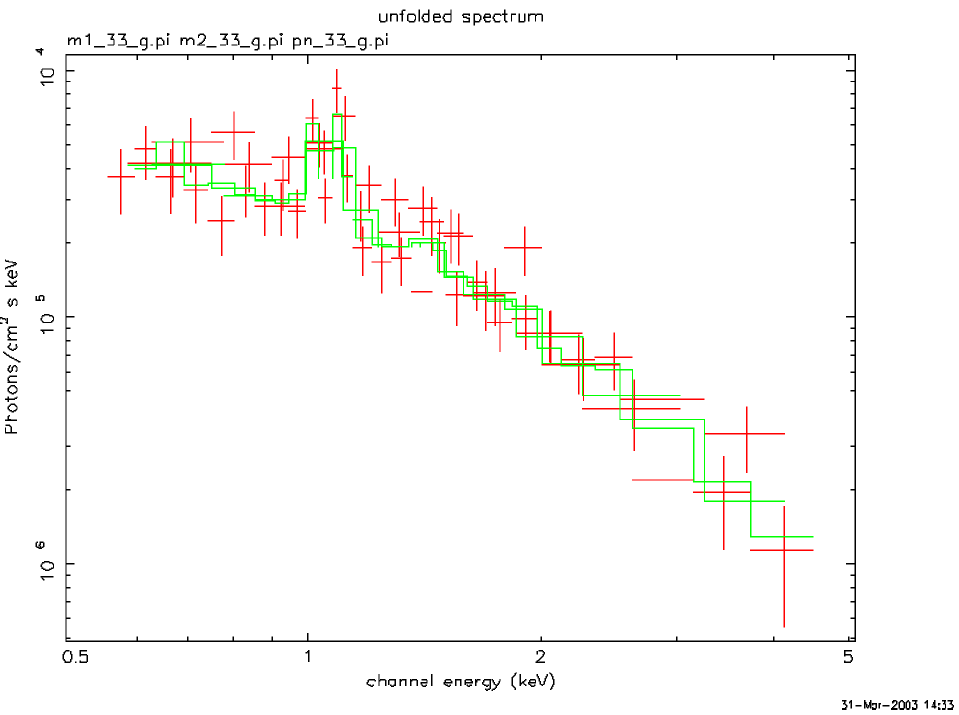
3C 449

Hot-gas environment determines lobe morphology

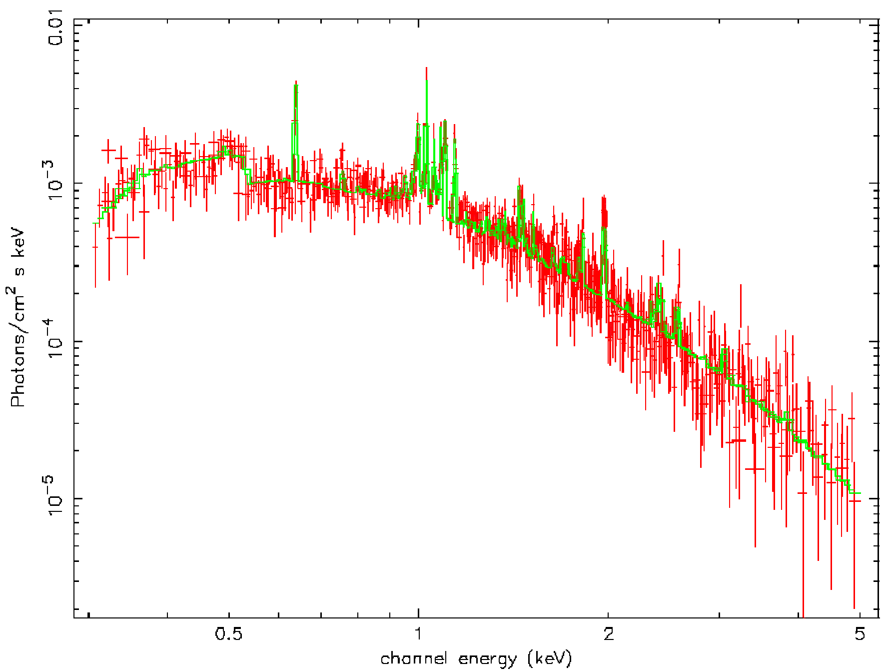


3C 66B
70 kpc
43 04
02
00
42 58
56
54
DECLINATION (J2000)
02 23 45
30
15
00
22 45
RIGHT ASCENSION (J2000)

Heated blob of gas



Blob of gas
kT = 2.4±0.3 keV



Environment
kT = 1.73±0.03 keV

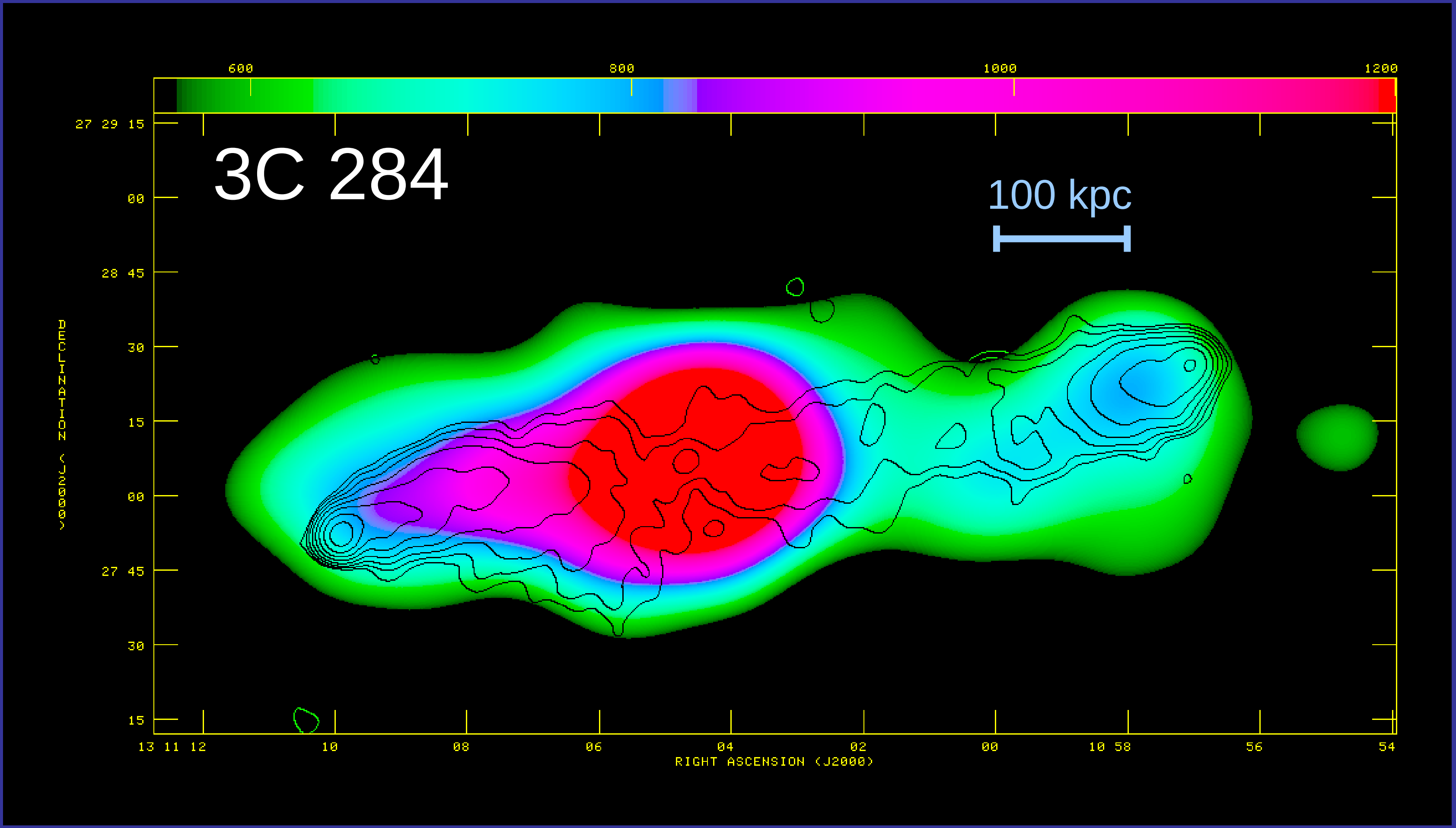
FR-I results

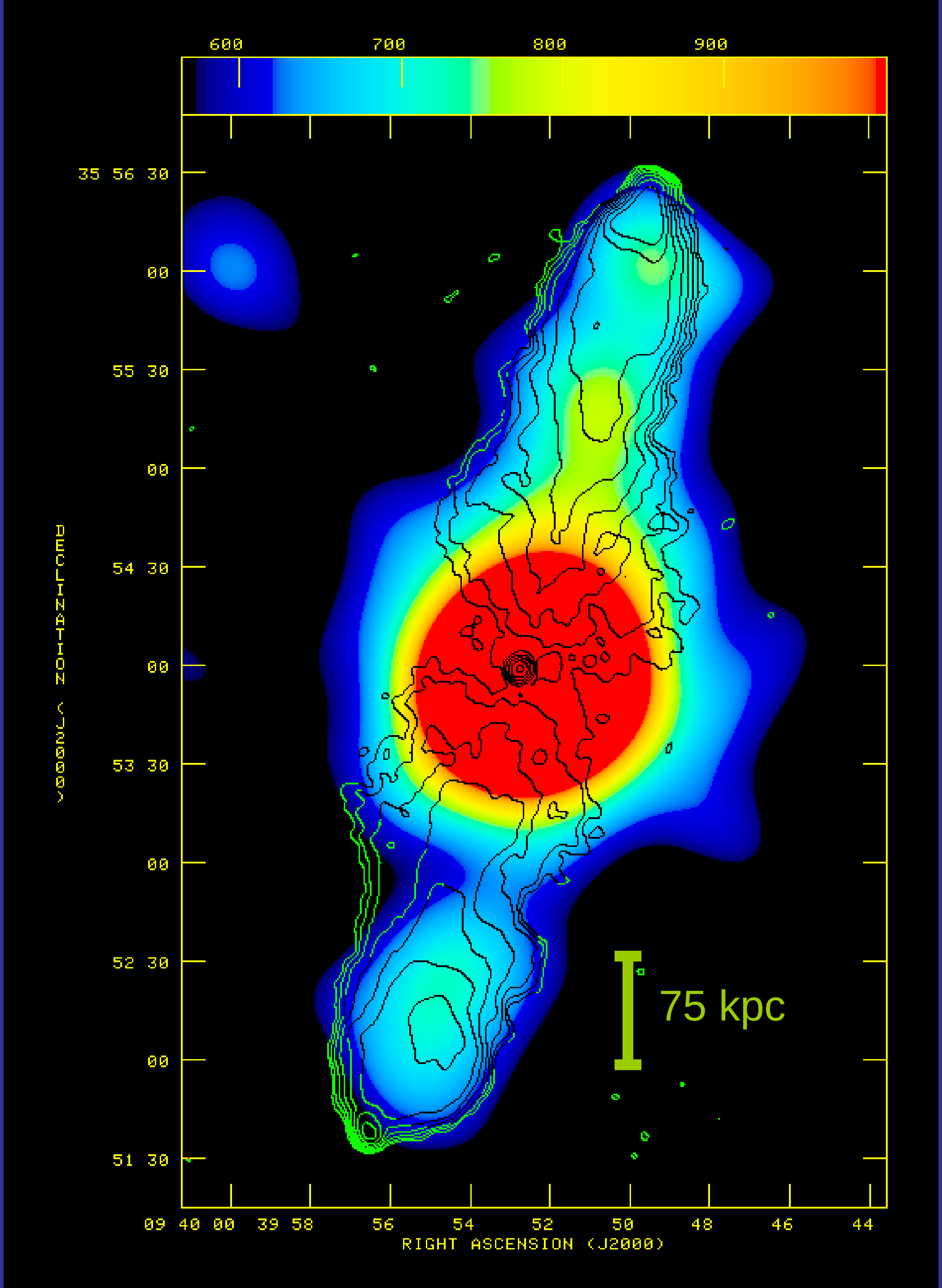
- Differences in gas density and distribution create varied lobe structures.
- Lobes must contain additional pressure source, as seen in other FR-Is. Heated, entrained gas? Relativistic protons? Magnetic domination?
- Blob of gas may be heated by work done on it by E jet of 3C 66B.
- More evidence for heating…
- Croston et al. (2003, MNRAS, 346, 1041)

2. Interactions in FR-IIs

- The environments of the most powerful FR-IIs (e.g. Cyg A) have been studied in detail.
- Typical FR-II environments are not well studied.
- FR-IIs may also need pressure contributions from other components (e.g. Hardcastle & Worrall 2000)
- Supersonic expansion should lead to shock-heating.
- Heating effects may become more widespread once lobe expansion is no longer supersonic in all directions.

XMM observations of FR-IIs

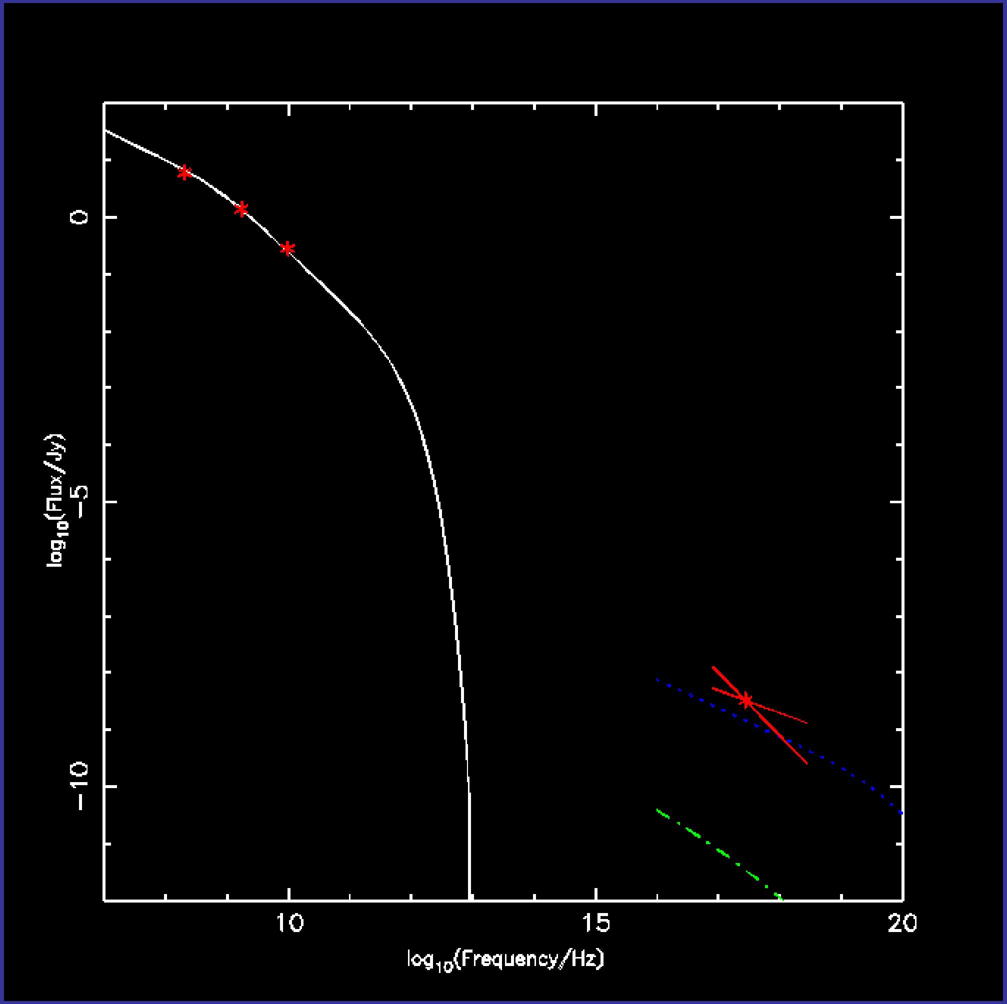




3C 223:

X-rays from the core, lobes and environment

Spectral models: lobes



3C 223 (N lobe)

- Modelled population of relativistic electrons using multi-frequency radio data.
- Spectral indices consistent with predicted IC.
- Measured flux within factor of 2.5 of predicted IC scattering of CMB.
- Magnetic field strengths ~0.5 nT.
- Within 25% of B_{eq} in all cases.

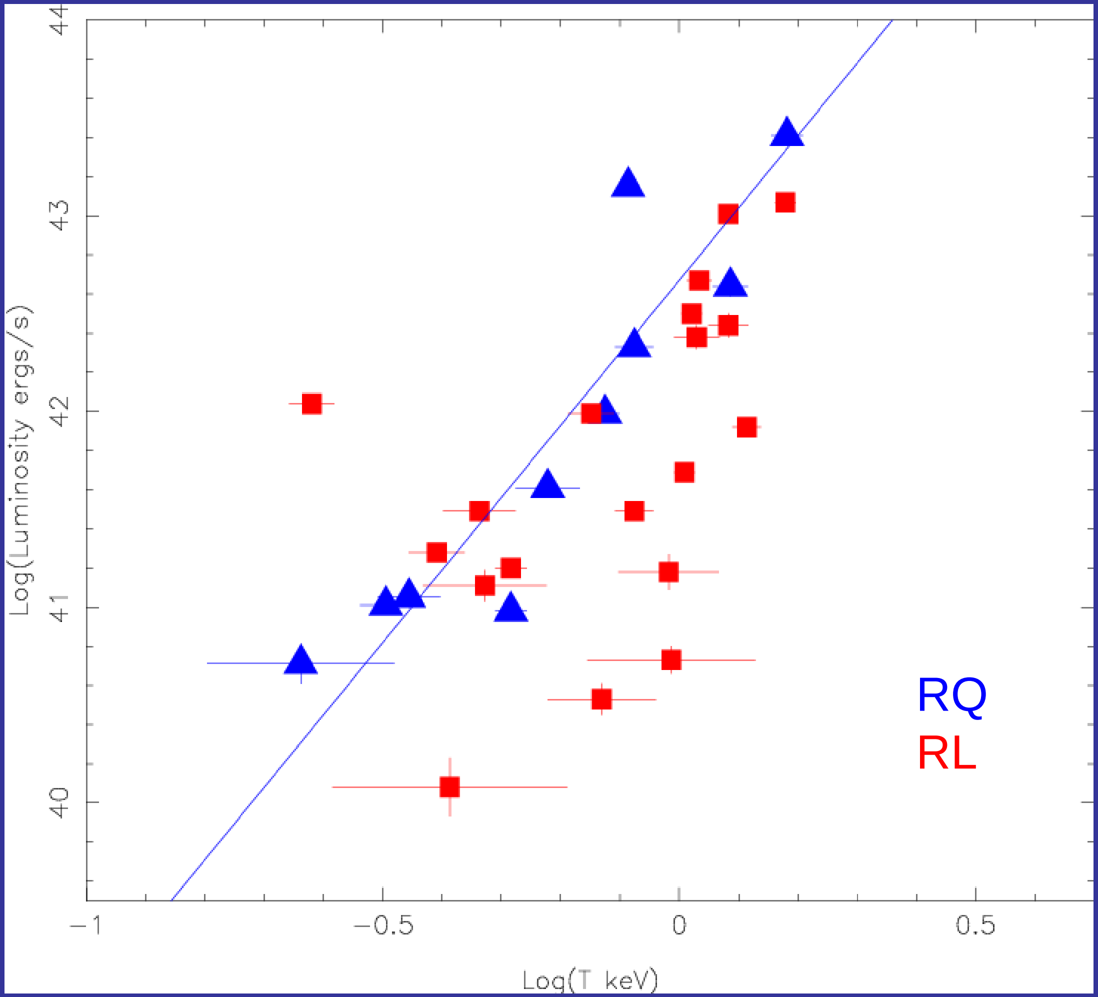
FR-II results

- Both sources have lobe-related X-ray emission, which is most plausibly IC scattering of CMB photons.
- B ranges from $0.75B_{eq}$ to B_{eq}.
- They are both in large group atmospheres with $L_x \sim 10^{43}$ ergs s^{-1}.
- External pressures are between 1.2 – 10 x the internal pressure from synchrotron-emitting electrons. Some additional material is needed. (However, neither source is likely to be very over-pressured).
- Heating effects? See later…

3. Heating in groups

- If radio-source heating is occurring in cluster cores so as to (at least partially) solve the "cooling-flow" problem, then it should also occur in groups.
- Heating effects will be more easily detectable in groups.
- We examined a sample of ROSAT observed groups (Osmond & Ponman, 2004) to see whether the gas properties of radio-quiet and radio-loud groups differ.
- A radio source was found in 18/29 groups.

L_x/T_x relations



- RQ/RL division in $L_{1.4GHz}$
- Trend fitted to RQ samples using OLS bisector.
- Compared distributions of ΔT_{eff} = perpendicular distance from best-fitting line.
- <5% prob. that RL and RQ groups are drawn from the same distribution.

What causes the temperature excess?

- Weak correlation between observed heating and radio luminosity.
- If the $E_{in}/L_{1.4}$ correlation is real:
  - the current radio galaxy is heating the gas,
  - or different generations of radio source in the same galaxy always have roughly the same power.
- But some RL groups don't show a temperature excess.
- Missing information: source ages and shapes.
- Maybe the picture is more complicated . . .

More complicated picture

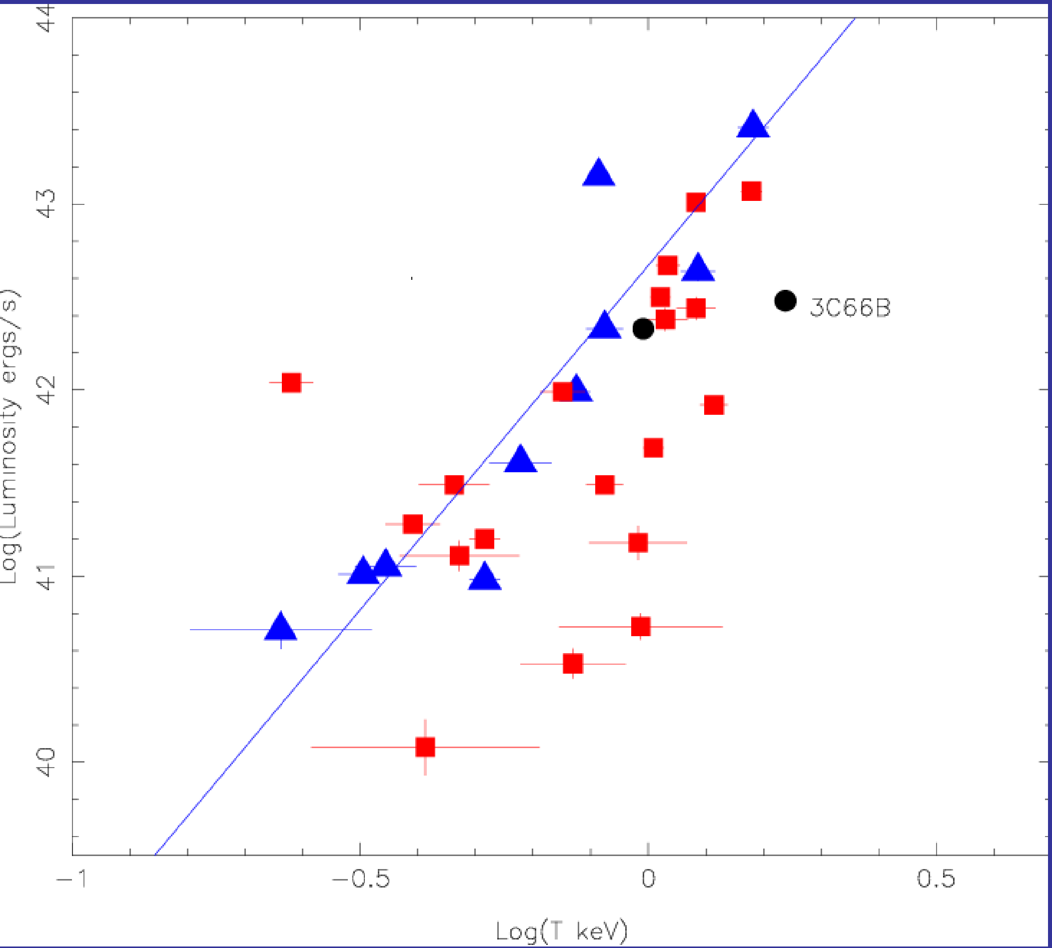
If the correlation does not hold, then either

- (a) Heating effects are long-lived: hot RL groups hosted powerful radio activity in the past, or
- (b) Heating effects are reasonably short-lived: hot RL groups are at a particular stage in the heating process.

If (a), we might find old, low-frequency radio emission from previous generations of radio source.

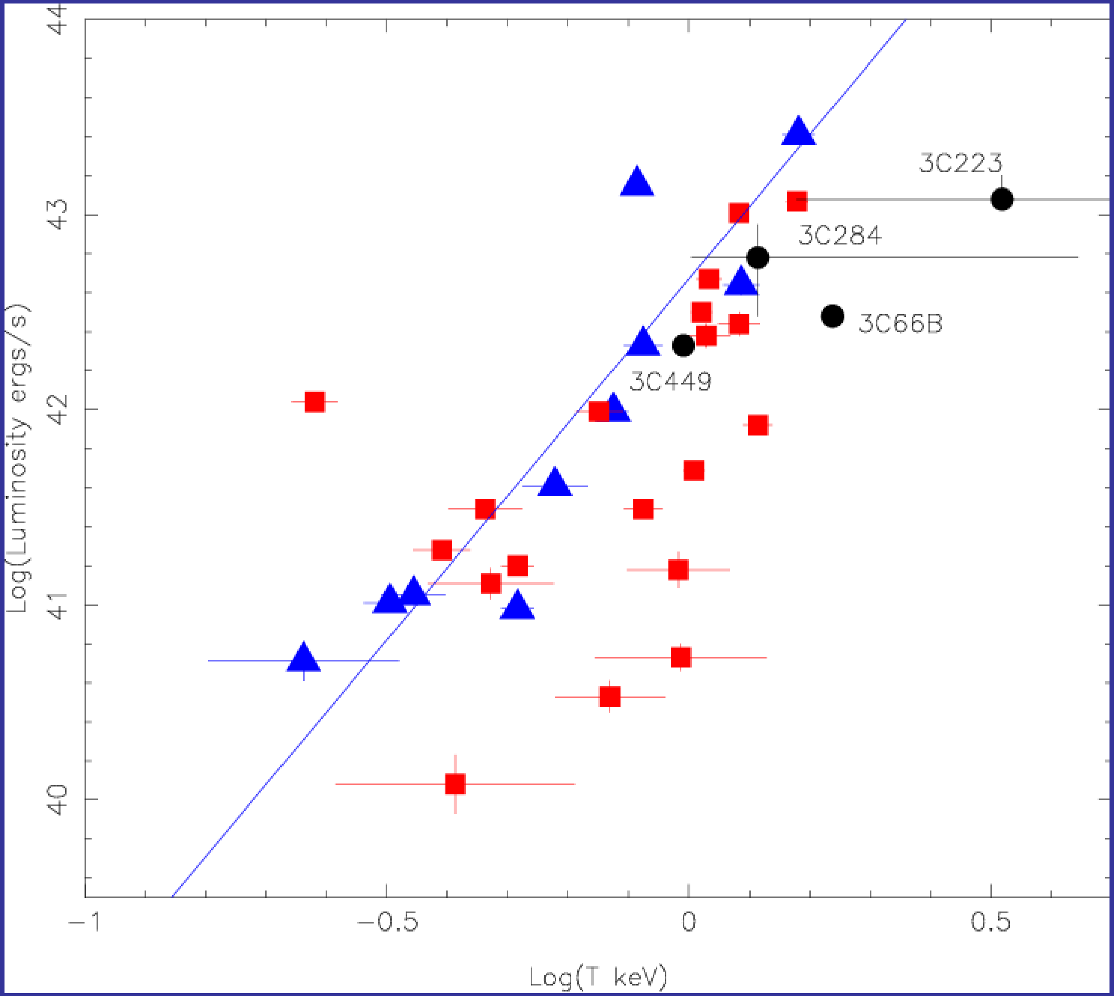
If (b), radio sources in the groups with temperature excess should be at a different stage of evolution to those without: not obviously true!

Heating in the FR-Is



- 3C 66B has T_{obs}=1.73±0.03 keV, and T_{pred} ~ 0.9 keV.
- If ~30% of the jet power of 3C 66B heats the group gas, it will produce the extra heating above the RQ relation in 3 x 10^8 years.
- If 3C 66B expanded mainly subsonically, it must be significantly older than its spectral age (~10^8 years).
- Current radio source 3C 66B is capable of producing this temperature increase.

Heating in the FR-IIs



- Radio-lobe structure of both sources suggests expansion no longer supersonic in all directions.
- 3C 223's high temperature suggests widespread heating.
- Both sources consistent with heating (but T poorly constrained).

Summary

- FR-Is
  - Morphology largely determined by interactions with hot-gas environment.
  - Pressure imbalance in FR-Is can be solved by: relativistic protons; heated, entrained material; magnetic domination.
- FR-IIs
  - Pressure imbalance less of a problem in FR-IIs; a small amount of protons or heated material could solve the problem.
  - Lobes of 3C 223 and 3C 284 have B fields near to equipartition.
- Radio-source heating
  - Evidence it's common in elliptical-dominated groups.
  - However, some RL groups DO NOT show heating.
  - Some direct evidence for radio-source heating by both FR-Is and FR-IIs.
- Future work: lobe dynamics, radio-source ages, and evolution of heated group gas. Larger samples: XMM?