The star formation histories of powerful radio galaxies

Dan Dicken
Institut d’Astrophysique Spatiale

Collaborators:
Clive Tadhunter, Sheffield
Raffaella Morgânti, ASTRON
Nicole Nesvadba, IAS
Matt Lehnert, Obs. Paris Meudon
Dave Axon
Andrew Robinson, RIT
Henrik Spoon, Cornell
Cristina Ramos-Almeida, IAC
Jo Holt, Leiden Observatory
Katherine Inskip, Max Planck
Preeti Kharb, RIT

Centaurus A, HST and Chandra composite image
Why study samples of radio galaxies?

- Radio galaxies hosts are almost invariably massive elliptical galaxies allowing clean selection and investigations of massive galaxy evolution
  - make up to 25% of the most massive galaxy population (Best et al. 2005)
  - because radio activity is short lived ($10^8$yr) implies radio activity is recurrent
- The mechanical energy from the radio jets interact heavily with the ISM making them excellent candidates for studies of AGN feedback
The original motivation: origin of the far-IR emission

- A compact uniform torus cannot produce the mid- to far-infrared spectral energy distribution (SED)
- This problem is solved by the clumpy torus model
- However, a compact torus + starburst can also explain the SEDs of AGN e.g. Rowan-Robinson (1995)

Compact uniform torus
Pier & Krolik (1994)

Clumpy torus
Nenkova et al. (2002)
Starbursts are thought to be the dominant heating mechanism of dust producing far-infrared emission in local LIRGs and ULIRGs (Although a significant AGN contribution is debated e.g. Imanishi et al. 2007)

These starbursts are triggered in mergers which could represent an important stage in the formation of massive galaxies

We might expect AGN activity and starbursts to be concurrent? i.e. the link between starburst, AGN and mergers?

Therefore, the origin of far-infrared emission is unclear

Clumpy torus vs. star formation

HST-ACS I-band images from the H-Goals survey (Evans et al. 2010). Images illustrate merger progression from relatively widely spaced pairs to advanced mergers for local luminous infrared galaxies
**Spitzer observations of the 2Jy sample**

**The 2Jy sample of southern radio galaxies**
- Comprises 88 objects with over two decades of multi-wavelength observation: Radio, X-ray, optical imaging and spectra, NIR etc
  - A radio flux limited sample $S_{2.7\,\text{GHz}}>2\,\text{Jy}$
  - delta<+10 degrees: ideal for ALMA

- Spitzer sub-sample of 46 steep spectrum selected radio galaxies and quasars taken from Tadhunter et al. (1993) and Morganti et al. (1993)
- Intermediate redshifts: $0.05<z<0.7$
- Optical Classifications
  - Broad-line radio galaxies/Quasar 35%
  - Narrow-line radio galaxies 43%
  - Weak-line radio galaxies 22%
- Radio Classifications
  - FRII 72%
  - FRI 13%
  - Compact Steep Spectrum 15%

**The 3CRR sample**
- Sub-sample of 19 FRII selected radio galaxies and quasars
- Low redshifts: $z<0.1$
- Optical Classifications
  - Broad-line radio galaxies/Quasar 16%
  - Narrow-line radio galaxies 58%
  - Weak-line radio galaxies 26%
The origin of mid- and far-infrared emission

- Optical L[[OIII]] emission line luminosity is a good indicator of AGN power (Tadhunter et al. 1998; Simpson 1998; la Massa 2010 etc)
- Correlations show that AGN illumination is the primary heating mechanism for the mid- and far-infrared emitting dust
- Find the same result when [OIII] replaced by mid-IR [OIV] $\lambda$25.9$\mu$m
Starburst Diagnostic Test 1: Optical Modelling

- We can identify objects with starburst populations from careful optical spectral synthesis modelling (Tadhunter et al. 2002; Wills et al. 2004, 2008; Holt et al. 2007)
- Starburst refers to “recent star formation activity” including all star formation activity that has occurred within 1.5 Gyr of the observation epoch, encompassing contemporaneous starbursts, continuous star formation, and post-starburst stellar populations
Starburst test 2: colour

- Optical identified starburst radio galaxies tend towards cooler mid- to far-infrared colours
• Starburst tracing PAH features were detected in IRS spectra
• The number of PAH detections in the powerful radio galaxy samples is low: 9 + 7 low equivalent width detections
With both PAH and optical identifications of starburst, far-infrared excess performs well as an indicator of starburst.
Results from the 4 starburst tests

**Starburst detections in the 2Jy and 3CRR samples**

<table>
<thead>
<tr>
<th>Name</th>
<th>other</th>
<th>Optical</th>
<th>PAH</th>
<th>Color</th>
<th>Par-IR</th>
<th>Name</th>
<th>other</th>
<th>Optical</th>
<th>PAH</th>
<th>Color</th>
<th>Par-IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0023−26</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>1814−63</td>
<td>U</td>
<td>low</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>0034−01</td>
<td>3C15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1839−48</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0035−02</td>
<td>3C17</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>1932−46</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>0038−09</td>
<td>3C18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1934−63</td>
<td>low</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0039−44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1938−15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0043−42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1949+02</td>
<td>3C403</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0105−16</td>
<td>3C32</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>1954−55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0117−15</td>
<td>3C38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2135−14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0213−13</td>
<td>3C62</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2135−20</td>
<td>OX−258</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>0235−19</td>
<td>OD−159</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2211−17</td>
<td>3C444</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>0282−71</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2221−42</td>
<td>3C445</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0347−05</td>
<td>U</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td>U</td>
<td>U</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0349−27</td>
<td>U</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td>2314+03</td>
<td>3C459</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>0404−03</td>
<td>3C105</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2356−61</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0409−75</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>3C33</td>
<td>low</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>0442−28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3C35</td>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0620−52</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>3C98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0625−35</td>
<td>OH−342</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DA249</td>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>0625−53</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3C152</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0806−10</td>
<td>3C195</td>
<td>low</td>
<td></td>
<td></td>
<td></td>
<td>4C73.08</td>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0859−25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3C236</td>
<td>(low)</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>0915−11</td>
<td>Hydra A</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>3C277.3</td>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>0945−07</td>
<td>3C227</td>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td>3C285</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>1136−13</td>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3C303</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>1151−34</td>
<td>U</td>
<td>low</td>
<td></td>
<td></td>
<td></td>
<td>3C305</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>1306−09</td>
<td>U</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>3C321</td>
<td>low</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>1355−41</td>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3C326</td>
<td>low</td>
<td>U</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>1547−79</td>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3C382</td>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>1559−02</td>
<td>3C327</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3C388</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1602−01</td>
<td>3C327.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3C390.3</td>
<td>U</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1648−05</td>
<td>Herc A</td>
<td></td>
<td>U</td>
<td>U</td>
<td>✓</td>
<td>3C452</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>1733−56</td>
<td>U</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

- Results from Dicken et al. (2012)
- A maximum of 35% of radio galaxies have evidence for starburst
Radio galaxies may not be triggered in major gas rich mergers?
• >85% of the sample show optical evidence for mergers (Ramos Almeida et al. 2011, 2012)
• Where is the star formation in radio galaxies?
• AGN Feedback is an obvious candidate to explain the absence of star formation e.g. outflows

• We have direct evidence for radio jet feedback in at least one object (3C326) (Nesvadba et al. 2010)

• Energy is driven into the galactic system: jets create turbulence, traced through shocked gas lines, inhibiting star formation
Returning to the morphologies: AGN triggering

**Pre-coalescence**
- Tidal tails, bridges

**Coalescence**
- Distorted morphologies and dust lanes

**Post-coalescence**
- Fans and shells
PKS 1733-56

PKS 2356-61

PKS 1934-63

Pre-coalescence
Tidal tails, bridges

Coalescence
Distorted morphologies and dust lanes

Post-coalescence
Fans and shells

- The lifetime of starburst and radio activity (≈100Myr) is much shorter than a merger (≈2.5Gyr)
- Should we expect to see starburst and AGN activity concurrently?
- We find no link between merger stage and the detection of recent star formation activity?
- The fact that radio activity can be triggered at any stage of a merger shows that we do not understand the triggering mechanism
- Our next step to understand the role of feedback is to trace the dust and gas content: is there fuel available for star formation?
  - Ongoing 3CRR CO observation campaign with IRAM
Interpreting the origin of the far-infrared emission

- **Caution:** need to be careful when making the assumption that the far-infrared (60µm) in AGN has a star formation origin
- >50% of our radio galaxy samples have LIRG/ULIRG far-infrared luminosities \((10^{11} - 10^{13} \text{L}_\odot)\) the majority with little or no evidence for recent star formation
- even at Herschel wavelengths \(\gg 100\mu\text{m}\): for non-starburst objects the mean 160/70µm = 2.2

- Disentangling the AGN from star formation contribution to the far-infrared emission will remain difficult
- Our best hope is to continue to improve our understanding of the far-infrared SED e.g. Mullaney et al. (2011)
- However, far-infrared excess can give reasonable upper and lower limits to the star formation contribution e.g. Seymour et al. (2011)
Conclusions

• There is good agreement between our four starburst diagnostics methods

• Recent star formation (<1.5Gyr) is only present in 22-35% of powerful radio galaxies

• Feedback processes are an obvious candidate to explain the absence of star formation

• However, radio galaxies are seen in a variety of merger stages, therefore starburst and AGN radio activity need not be concurrent

• The dominant heating mechanism for the far-infrared emission from radio galaxies is the AGN and not star formation

• Caution is needed when interpreting observations of wavelengths >60µm as indicator of star formation
This site presents the objects and data from over 20 years of collaborative work on the 2 Jansky sample of southern radio galaxies with flux density above 2 Jansky at 2.7GHz and delta-<+10 degrees.

Two decades of observations has led to a wealth of data for these objects including: Deep optical imaging and spectra from Gemini and the WHT as well as extensive radio imaging/mapping from ATCA and the VLA. For 47 objects with 0.05<z<0.7 the sample is also complete at mid to far-infrared wavelengths for imaging and spectra with Spitzer, high frequency radio core imaging with ATCA and the VLA. Additionally a large proportion of objects have recently being observed with Chandra and 38 objects have deep 2.2 micron near infrared imaging.

Included in this site is a description of the sample, tables of basic parameters and data for all the objects, individual object pages where you can download available reduced data and see some of the available images and spectra. Additionally there are also links to all the major publications related to the sample. We hope this site will be a useful resource for you, but don’t hesitate to contact us if you have any questions.

Although this website will run on Internet Explorer it is best viewed in a standards compliant browser such as Firefox or Safari.

http://2jy.extragalactic.info/