The Unification of Powerful Quasars and Radio Galaxies and Their Relation to Massive Galaxies

Pece Podigachoski[1], Peter Barthel[1], Martin Haas[2],
Christian Leipski[3], Belinda Wilkes[4], et al.

Goal: Investigate the interplay between star formation and AGN activity in the most massive galaxies: the hosts of radio-loud AGN. Test the unified model for powerful, radio-loud AGN using orientation-indicators and orientation-invariants.

Method: *Herschel* (PACS and SPIRE) photometry: assess the far-infrared spectral energy distribution properties of high-redshift (z>1) 3CR radio galaxies and quasars.

Results: Prodigious star formation activity in 40% of sample. No sign of negative feedback. Hints for jet-triggered star formation in hosts of subgalactic-sized radio sources. Support for the unified model for powerful, radio-loud AGN.

Motivation

Black hole accretion and star formation went through peak activity at z~2, thus probing active massive galaxies in this redshift range is arguably the best strategy to constrain the coeval black hole and host galaxy growth. *Herschel* allows us to quantify the dust emission from active galaxies over cosmic time, and thus to address the respective contributions from black hole accretion and star formation.

Data analysis

Our sample, the complete Revised Third Cambridge Catalogue (3CR) of sources with z > 1, is the brightest low-frequency-selected (i.e. orientation unbiased) radio-loud AGN sample. This sample was imaged as part of our *Herschel* Guaranteed Time project '*The Herschel Legacy of distant radio-loud AGN*' (PI: Barthel). Using ancillary *Spitzer* data, we fit the full infrared spectral energy distributions of the 3CR hosts, with a sum of several components (old/new stars, torus) accounting for the emission at different wavelengths .

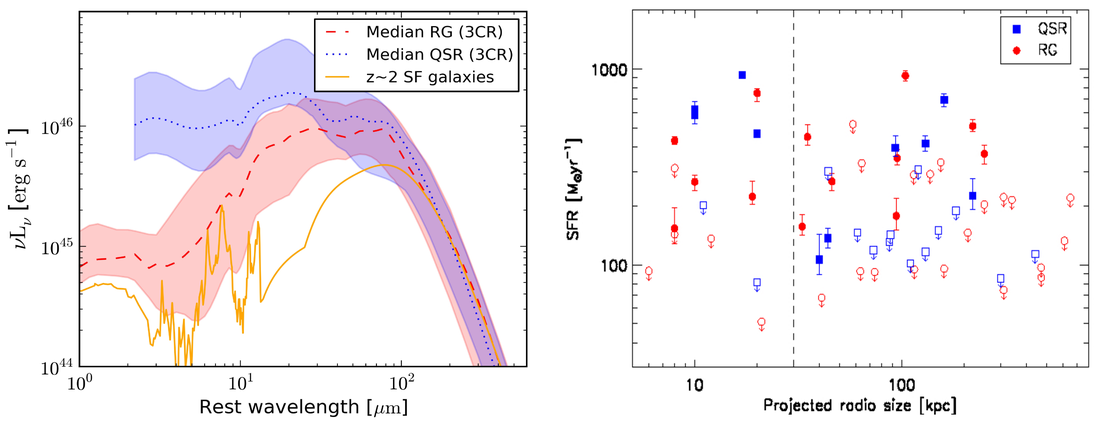

Fig.1 (Left) Average infrared spectral energy distributions for radio galaxies (red), quasars (blue), and a comparison sample of star-forming galaxies (yellow) from Kirkpatrick et al. (2012). (Right) Star formation rate as a function of projected radio size for radio galaxies (red) and quasars (blue). The dashed line indicates the value separating subgalactic-sized (<30 kpc) and supergalactic-sized (>30 kpc) radio sources.

Results

About 40% of our objects undergo episodes of prodigious star formation, with rates of hundreds of solar masses per year, comparable to equally massive, non-active galaxies at these redshifts (Podigachoski et al. 2015a). The average infrared spectral energy distributions of radio galaxies and quasars (Figure 1, left) differ strongly in the mid-infrared (1-10 μm) regime, but are remarkably similar at wavelengths longer than ~40 μm.

Despite the often dominating powerful AGN activity, we find no evidence for uniform quenching of star formation (negative feedback) within 3CR hosts. We find that most of the subgalactic-sized (<30 kpc) radio sources are associated with strongly star-forming hosts, suggesting the occurrence of jet-triggered star formation (positive feedback, Figure 1, right). Follow-up high-resolution ALMA studies of selected sources (awarded in ALMA Cycle 3) will allow us to pinpoint the exact location of the star formation activity, and possibly link it to the radio-jet activity.

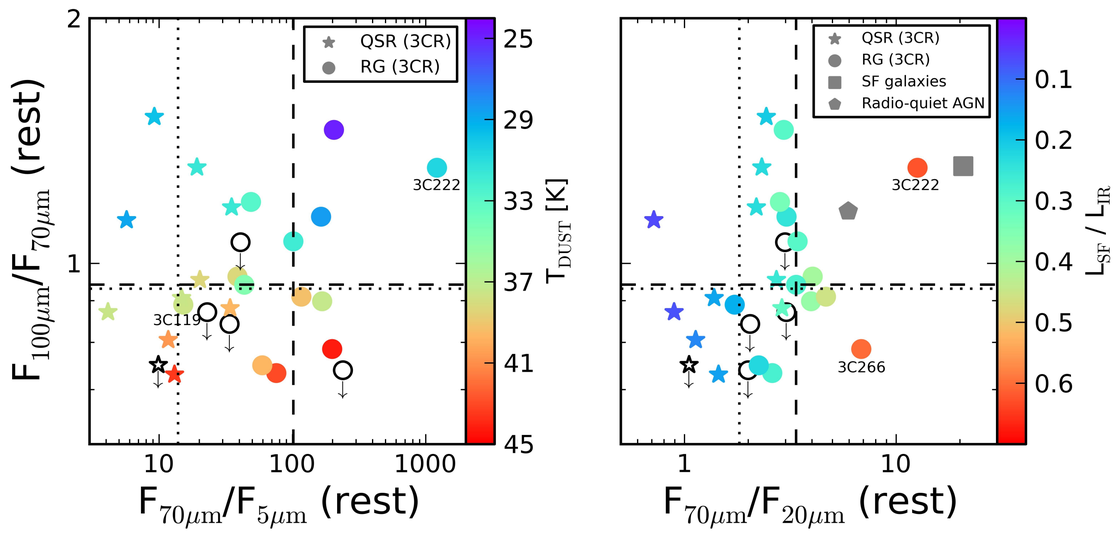

Fig.2 Rest-frame infrared color–color diagrams. Filled colored symbols (stars for quasars and circles for radio galaxies) represent objects detected in at least three *Herschel* bands, whereas empty symbols represent objects detected in only the two shortest *Herschel* bands. Dotted and dashed lines mark the corresponding median colors of quasars and radio galaxies, respectively. (Left) 3CR objects are color-coded according to their cold dust temperatures. (Right) 3CR objects are color-coded according to their fractional star formation luminosity. Gray symbols show the median colors of the comparison star-forming galaxies at z ~ 2 (square) and radio-quiet AGN (pentagon), both from Kirkpatrick et al. (2012).

We create infrared color-color diagrams for the 3CR hosts detected in the *Herschel* SPIRE bands, finding that while the mid-infrared emission is anisotropic, the far-infrared emission is isotropic and optically thin (Figure 2, left). These findings are consistent with the orientation-based unification of radio-loud AGN (Podigachoski et al. 2015b). Minimizing the obscuration in the mid-infrared, we use the mid- to far-infrared color as a diagnostic to probe the relative importance of the star formation and AGN activity to the total infrared luminosity (Figure 2, right).

References:

Kirkpatrick et al. 2012, ApJ, 759, 139;
Podigachoski et al. 2015a, A&A, 575, 80;
Podigachoski et al. 2015b, ApJL, 806, L11

1. University of Groningen, NL
2. University of Bochum, DE
3. Max Planck Institute for Astronomy, DE
4. Harvard-Smithsonian CfA, US

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Contact: podigachoski@astro.rug.nl

rijksuniversiteit groningen