Follow-up of Radio Loud AGN from the South Pole Telescope Survey

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Abstract

A study of radio-loud AGN in ~1500 square degrees of the South Pole Telescope point-source survey has revealed three classes of sources: radio-loud quasars whose radio to sub-mm SED is a flat power law, radio-loud quasars whose spectrum turns over due to self-absorption between 20 and 150 GHz and sources with an upturning spectrum in the far-infrared. The upturning spectrum has an apparent excess flux of 5-84 mJy at 1.4mm and may be due to thermal emission from dust. If the upturn is due to thermal emission, the implied far-infrared luminosities are huge, and the sources are ultra-luminous infrared galaxies (ULIRG: L>$10^{12}L_\odot$). Despite this, none of the upturning sources are detected by Planck and IRAS. Follow-up spectroscopy, of a sub-sample of upturns with VLT-ISAAC, indicates that these ATCA-identified, upturning radio sources are typically broad line radio-QSOs at z=1.0-2.3 with or without a thermal dust component. Possible scenarios are discussed to explain these observations.

SPT Observations[1]

- 10m sub/mm telescope at the South Pole.
- The South Pole is an ideal site for IR observations. The atmosphere is very dry due to the high altitude and the extreme cold, plus the long winters reduce variability from the Sun, creating a stable atmosphere.
 Designed to detect clusters through SZ effect.
- Also detects fine-scale CMB anisotropies and **mm point sources** – the latter the subject of this work.
- Observes at 90, 150 & 220 GHz **simultaneously**.
- We are looking at sources in a ~**1500 sq deg** patch of the completed 2500 sq deg survey.

Selection

- Firstly the SPT sources were cross correlated with **ATCA/AT20G**[2] (20 GHz). Sources were matched if their separation was less than 10".
- A 20 GHz detection (AT20G flux limit 40 mJy) implies synchrotron emission and hence an **AGN**.
- The SPT radio sources were divide into 3 classes based on spectral index ($S \propto \nu^{\alpha}$):

Upturn (30%) $\alpha_{150}^{220} > 0$ | Non-thermal (63%) $\alpha_{150}^{220} < 0$ | Peakers (7%) $\alpha_{20}^{90} > 0$

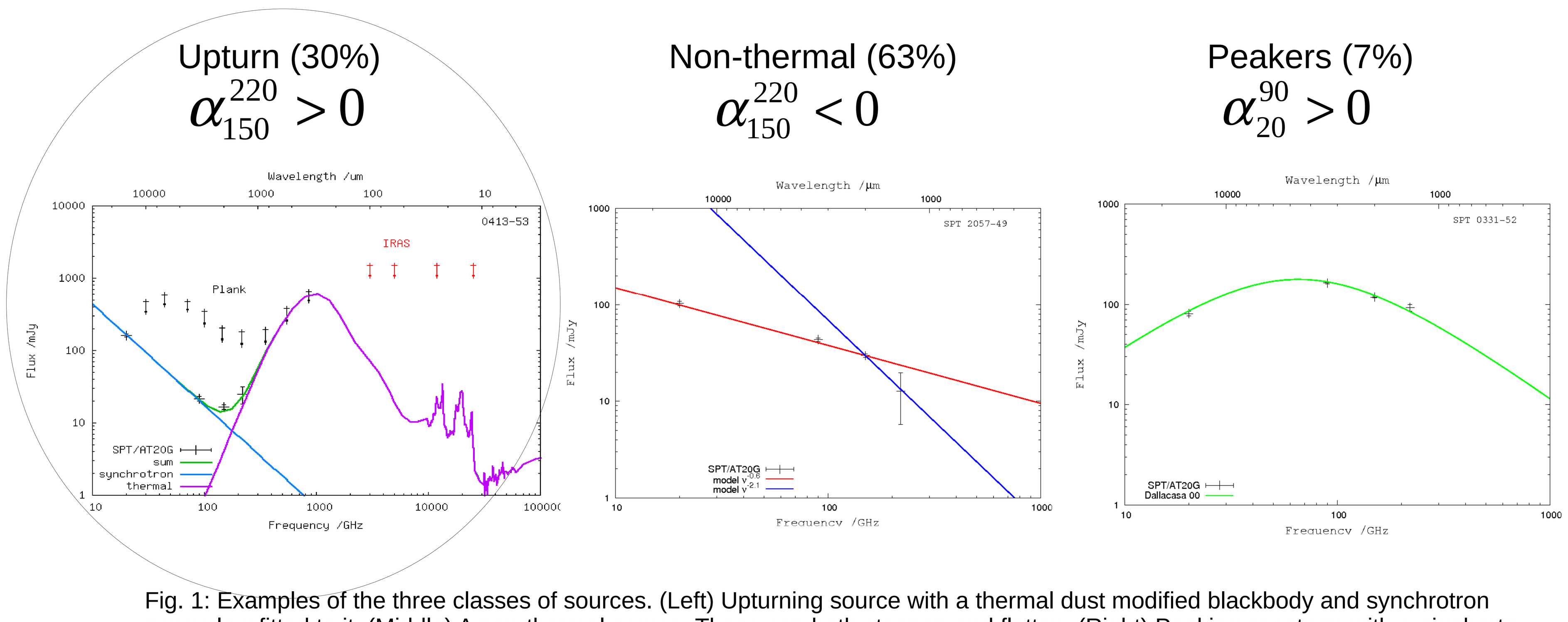


Fig. 1: Examples of the three classes of sources. (Left) Upturning source with a thermal dust modified blackbody and synchrotron power-law fitted to it. (Middle) A non-thermal source. These can both steepen and flatten. (Right) Peaking spectrum with a gigahertz peaked spectrum (GPS) fitted.

Upturn

- This work explores the properties of the upturning, SPT radio sources (17% of the AGN sample). They are shown, along with the other sources, in Figure 2 below.
- Selection plots show **no correlation** between the upturning spectral index between 220 and 150 GHz and the spectral index at lower frequencies.

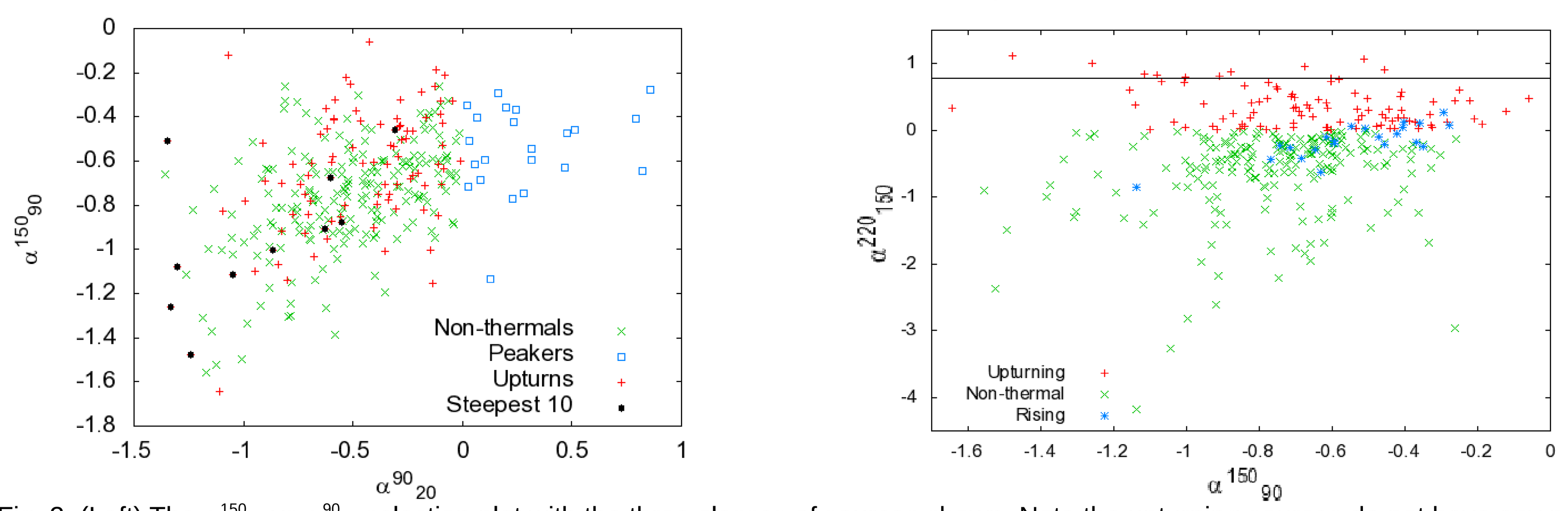
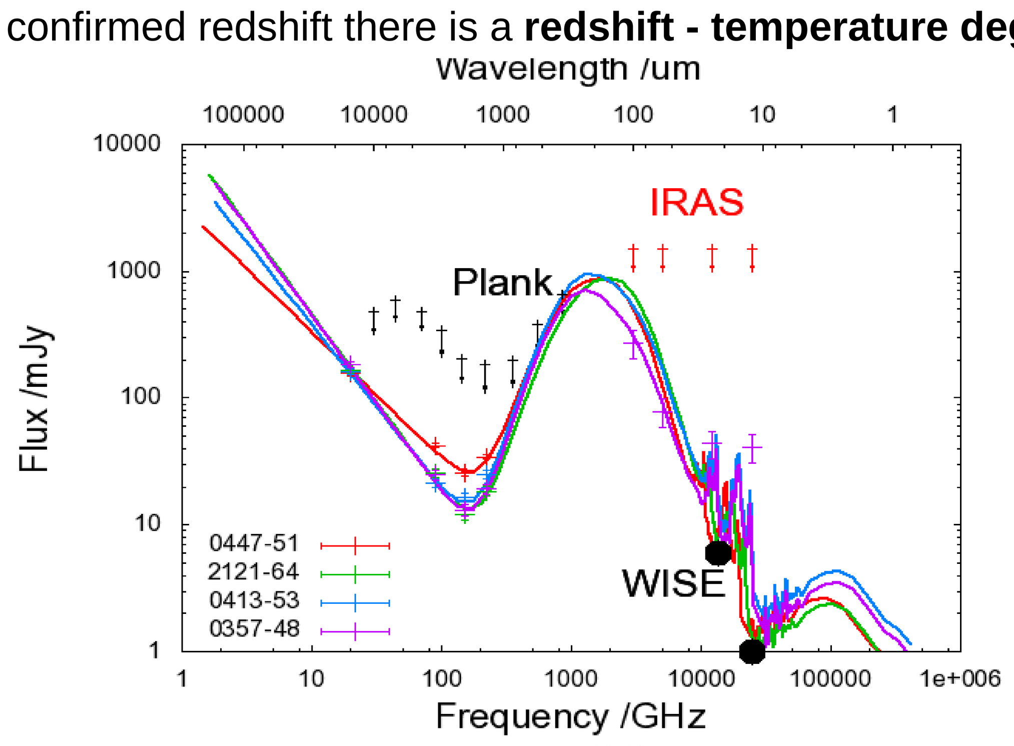


Fig. 2: (Left) The α^{150}_{90} vs α^{90}_{20} selection plot with the three classes of sources shown. Note the upturning sources do not have any particular synchrotron slope. (Right) The α^{220}_{150} vs α^{150}_{90} selection plot with the cutoff for the ten most upturning sources shown.

- Analysis involves fitting a thermal dust model[3] and a synchrotron power law to sources (see Figure 3).
- This model is constrained by non-detections in Planck and IRAS and some detections in WISE.
- Without a confirmed redshift there is a **redshift - temperature degeneracy** in fitting the model.



$$\downarrow T \approx \uparrow z$$

Fig. 3: The thermal dust model fit to 4 of the steepest upturns with WISE detections. Note 0357-48 has a 4σ IRAS detections confirming the upturn.

- The implied IR luminosity is of the order of $10^{12\text{-}13}$ $L_\odot$, classing sources as **ULIRG/HyLIRGs**.
- The maximum star formation rate this implies[4] (i.e. if this dust arises wholly from star formation) is of the order of a few thousand $M_\odot$/yr. Although the actual rate will be significantly lower (or possibly zero) due to the AGN contribution to dust heating.

Spectroscopy

- To determine the nature of these sources and confirm the redshift, VLT/ISAAC zJHK spectroscopy of 14 sources and JK imaging of 7 was carried out.

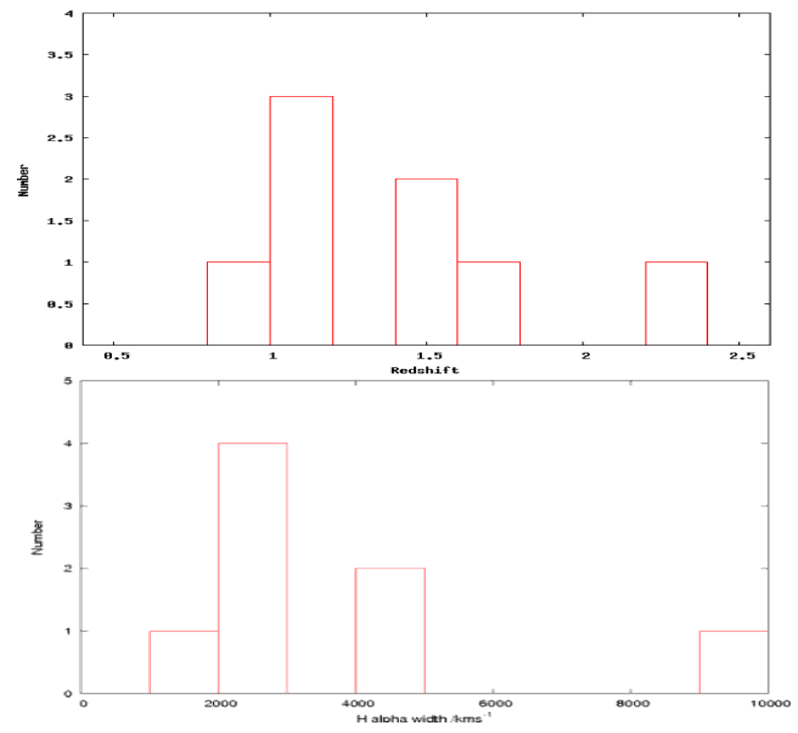


Fig. 4: The redshift (top) and FWHM (bottom) distribution of the sources observed. All sources observed have broad Hα and hence contain AGN.

- Broad Hα lines indicate a **strong AGN** component (see Figure 4). These were fitted with the sum of a broad and intermediate-width Gaussian as in Orellana '11[5] (see Figure 5R).
- Also detected Hβ and oxygen lines, usually in the z band (see Figure 5L).
- J-K,K CMD diagrams show **no evidence** for the sources being part of a **cluster**.
- BPT diagram positions could not be obtained for the majority as the necessary lines were often not observed.

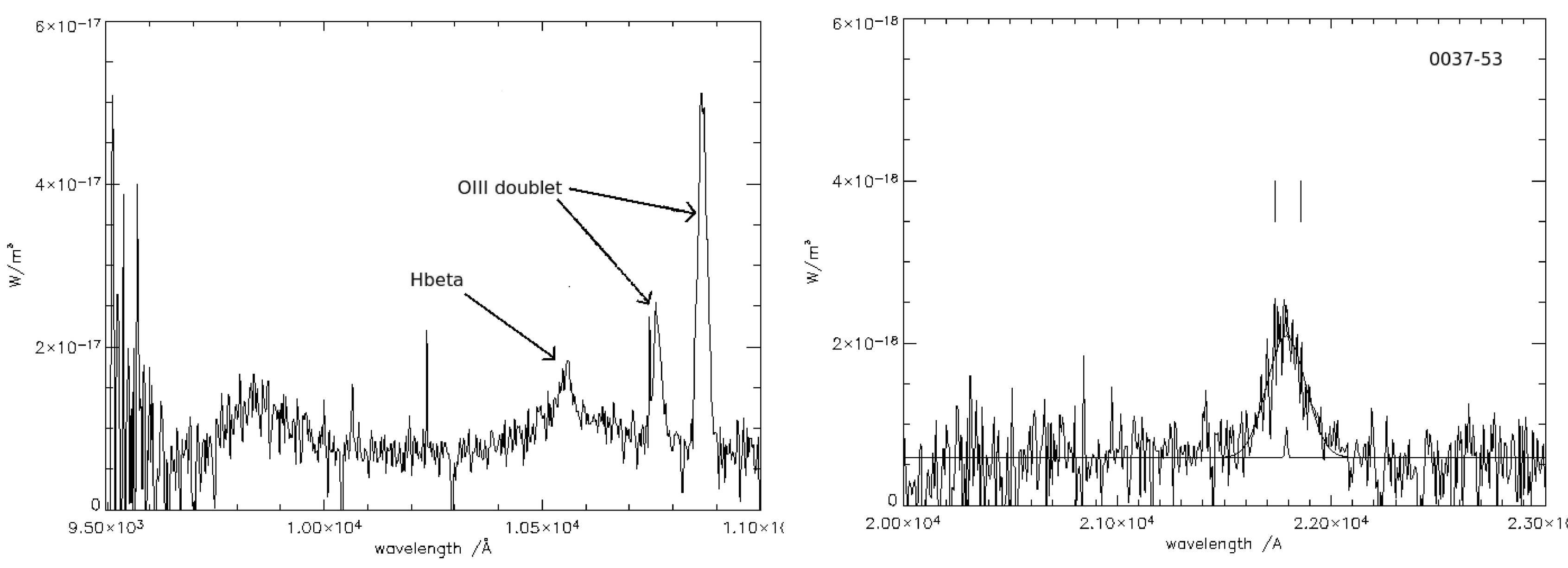


Fig. 5: (Left) An example z band spectrum showing typical lines. (Right) An example Ha line (in the K band) which has been fit with a broad and intermediate/narrow width Gaussian. The two lines above mark the position of the NII doublet.

ULIRG+FSRQ vs FSRQ

- These sources are clear FSRQ but their SED allows a thermal dust component if they are ULIRGs or no thermal component if the upturn is due to some other process or statistical fluctuation (see Figure 5). It is hard to explain the upturn without a thermal component as the SPT points are simultaneous.
- The obvious next step is to confirm the extent of the upturn with APEX LABOCA & SABOCA at 870 μm and 350 μm respectively.
- For the sources with confirmed redshifts of between 1 and 2.5 the SABOCA wavelength lies near the peak of any thermal dust emission and hence should be easily detectable.

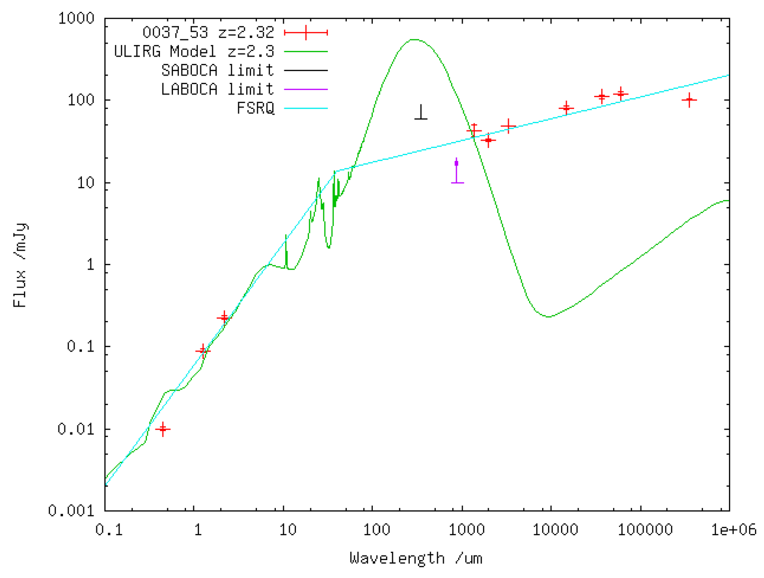


Fig. 5: The SED of one source, which has a spectroscopic redshift of 2.3, with a ULIRG and FSRQ model overlaid in green and blue respectively. The flux limits of SABOCA and LABOCA are also shown.

Conclusions

We have discovered a rare population of high redshift, broad-line AGN sources in the SPT survey that are either FSRQ or combined FSRQ and ULIRG/HyLIRGs. Future work is needed to confirm the nature of these sources. Submm observations with APEX will confirm or rule out the thermal dust origin of the upturn thereby determining the nature of the sources. In addition SPT maps and radio data can be explored for variability to see if this provides an alternative explanation. Work is ongoing.

References & Acknowledgments

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