Tunable filter imaging: structure forming around a quasar at \( z = 0.9 \)

Joanne C. Baker

MRAO, Cavendish Laboratory, Madingley Road, Cambridge CB3 0HE, UK

Abstract.

Preliminary results are described for emission-line imaging of the field of a quasar at \( z = 0.9 \) with a unique new instrument — the TAURUS Tunable Filter (TTF). At least fourteen \([\text{O} \text{ II}]\)-emitting galaxy candidates are found within \( \pm 750 \text{ km s}^{-1} \) of the quasar redshift with a significance of \( > 3\sigma \). Another eight candidates \( (> 3\sigma) \) are also found with relative velocities \( \pm 750 - 1500 \text{ km s}^{-1} \) from the quasar, indicative of a large velocity dispersion in the field. Together with the existence of a group of red galaxies in the field identified through broad-band imaging, we suggest that the TTF data are probing cluster merging which is ongoing at \( z = 0.9 \).

1. Introduction

The search for emission-line galaxies at high-redshift is important for tracing the history of star formation in the universe. Variations in the rate at which galaxies are forming stars are apparent in regions of different galactic density. For example, lower star formation rates have been measured in rich galaxy clusters (Balogh et al. 1997) than in the field (Cowie et al. 1997).

As part of a major program (in collaboration with Bremer, Hunstead and Bland-Hawthorn) to find high-redshift galaxies and clusters, deep narrow-band imaging of the fields of \( z \sim 1 \) radio-loud quasars has been obtained using a new instrument — the TAURUS Tunable Filter (TTF). At lower redshifts \( (z < 0.7) \) it has been shown that radio-loud quasars tend to favour rich environments (Yee & Green 1987), and this makes them good pointers to overdense regions at high redshift.

The TTF is a Fabry-Perot-based imaging system developed recently at the Anglo-Australian Telescope (AAT) enabling, for the first time, sensitive narrow-band imaging with a minimum tunable bandpass of \( \sim 10\text{Å} \) (Bland-Hawthorn & Jones 1997). The high throughput and narrow bands achievable with TTF enable the detection of galaxies at \( z \sim 1 \) with star formation rates of one solar mass per year and higher via their \([\text{O} \text{ II}] \lambda 3727 \) emission lines. This contribution describes the detection of \([\text{O} \text{ II}] \) emitting galaxies with TTF around a quasar at \( z = 0.9 \) (our first target).
Figure 1. Sub-images drawn from a sequence of seven 1000s TTF images of the field of the $z = 0.898$ quasar MRC 0450−221, taken in 10Å FWHM adjoining passbands spanning redshifted [O II] (column 4). Extended [O II] emission is clearly seen around the quasar (Q) elongated in the direction of the radio axis. Two galaxies (G1 & G2) with line emission within 500 km s$^{-1}$ of the quasar redshift are also shown. Each sub-image spans about 500 km s$^{-1}$ at this redshift.

2. TTF imaging of a quasar at $z = 0.9$

The quasar MRC 0450−221 was observed with TTF at the AAT in February 1997 in a sequence of seven 10Å-wide bands centred on [O II] at the quasar redshift, $z = 0.898$. Exposure times were 1000s per band, and the seeing typically 1.3$''$ FWHM. Figure 1 shows sub-images drawn from the sequence of TTF images of the $10' \times 10'$ field centred on MRC 0450−221. Extended line emission around the quasar (Q), reaching up to 1000 km s$^{-1}$ redward of the nuclear emission, and two emission-line galaxies (G1 & G2) lying within 500 km s$^{-1}$ of the quasar redshift are displayed in three panels. Each sub-image spans about 500 km s$^{-1}$ at this redshift.

To identify emission-line galaxies at the quasar redshift, average images were made centred on $(\pm 750$ km s$^{-1}$) and off $(\pm 750 - 1500$ km s$^{-1}$) the quasar [O II] wavelength as a first step. Images at the central three wavelengths (i.e. bands 3,4,5 in Figure 1) were added together to form the on-band image, and the remaining four images co-added to form an average off-band image. In practice, a combined image of all seven frames was used for the off-band image, as this was deeper and the measured magnitudes did not differ significantly from the 4-frame off-band image. All the following analysis was performed on both off-band frames to confirm the results.

For each co-added image, aperture photometry was carried out on the central $7' \times 7'$ using FOCAS. A three-pixel aperture radius (2$''$) was used, and the final magnitudes corrected by a constant factor to account for missing flux. This factor was measured from stars in the field to be a constant 0.4 mag difference over the whole magnitude range, giving total corrected magnitudes which were in excellent agreement with those measured using a larger aperture. The small
aperture size was chosen to optimise signal-to-noise for our mainly small and faint targets. A finding list was then made from the deep combined image, and the list was matched to the other catalogues of objects detected by the FOCAS algorithms. Photometric uncertainties in the on-band image are about 0.2mag at 21 mag (1σ at 7070 Å).

Emission-line galaxies have been identified on the basis of the above photometry (a range of other photometric techniques were tried, and give consistent results). Fourteen candidates fainter than 18.5 mag with excess emission ±750 km s$^{-1}$ from the quasar redshift (i.e. brighter in the on-band image) with a significance of $>3\sigma$ are found and are shown on the colour-magnitude diagram in Figure 2. These fourteen candidates comprise 20% of all the objects fainter than 18.5 mag with positive magnitude differences in Figure 2, which clearly exceed the proportion expected due to noise alone.

Line emitting galaxies over a large range of velocities relative to the quasar redshift ($\pm750 - 1500$ km s$^{-1}$) are also seen in the field, as indicated by objects with significant but negative magnitude differences in Figure 2, i.e. eight objects $>3\sigma$. The identification of such objects as emission-line galaxies can be confirmed by inspecting magnitudes in the seven TTF wavelength bins, such that they appear much brighter in one or two bands. Therefore, a large velocity dispersion is inferred for the emission-line galaxies in this field, at least $\pm1500$ km s$^{-1}$.
3. Discussion: subcluster merging at $z = 0.9$?

The number of emission-line galaxies found in our TTF survey ($\sim 22$) exceeds the expected value of 1-2 line-emitting field galaxies at $z = 0.9$ in the volume surveyed, based on the space densities of Cowie et al. (1997). The detections have been confirmed by visual inspection on TTF images and $R$ and $I$ broad-band images of the field. The faint magnitudes and broad-band colours of the candidates make it highly likely that they are at the quasar redshift rather than being intervening H$\alpha$ or [O III] emitters (spectroscopic confirmation is being sought), although about 3-4 low-redshift contaminants are expected in the TTF data according to the numbers of Cowie et al. (1997). Assuming the line-emitting objects lie at $z = 0.9$, the implied [O II] equivalent widths range between 30-300 ˚A and reach star formation rates of a few solar masses per year, consistent with values derived for field galaxies (Cowie et al. 1997).

The overdensity of star-forming galaxies in the field of MRC 0450$-$221 suggests the existence of a cluster, which is supported by observations of a group of red galaxies which is visible to the southeast of and around the quasar. The red galaxies ($R - I > 1$) have colours consistent with being passively-evolving ellipticals at $z = 0.9$. An investigation of the relationship between the emission-line galaxies identified above and the red galaxy group in the field is ongoing — the candidate [O II]-emitters appear to cluster around the quasar, but more weakly than the red galaxies. It is possible that the star-forming galaxies are infalling towards an older cluster core traced by the red galaxies. Such a picture would be expected at $z \sim 0.9$ if clusters form hierarchically.

4. Conclusions

Using TTF, twenty-two emission-line galaxies are detected in the field of the $z \sim 0.9$ quasar MRC 0450$-$221 with a significance of greater than 3$\sigma$. The presence of star forming galaxies around the quasar, together with an overdensity of red galaxies in the field suggests that the quasar lies in, or near a cluster at $z \sim 0.9$. The large velocity dispersion in the field suggests that the line-emitting galaxies probed by TTF are infalling onto the older cluster core, and perhaps lie in merging subclumps.

A full analysis of this field will be published shortly (Baker et al. in prep). TTF observations of more $z \sim 1$ quasar fields are ongoing and will address the properties of high-redshift clusters and their relationship with quasar activity.

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References

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