Resolving a starburst/AGN at z = 2.3?

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ABSTRACT

The interaction between star formation and supermassive black hole activity is one of the key challenges in modern astrophysics. One of the most famous cosmic laboratories for studying this interplay is the gravitationally lensed, starburst/AGN composite galaxy ***IRAS FSC10214+47****, which has been the topic of > 100 publications over the past 19 years. Observations across the EM spectrum from X-ray to radio wavelengths reveal puzzling and sometimes contradictory features. We report the high spatial resolution radio properties of this enigmatic object through MERLIN 1.6 GHz and VLA (A-array) 8 GHz observations. Furthermore, we present the mid-infrared through radio spectral energy distribution which includes two new observations at 330 MHz (GMRT) and 15 GHz (Ryle Telescope). We compare the infrared SED with the starburst templates of Rieke et al (2009) and obscured quasar dusty torus template of Fritz et al (2005).*

HST & MERLIN

The result of the 24 hour MERLIN 1.6 GHz observation is shown in Fig. 1 with Hubble Space Telescope contours overlaid. The HST map is a combination of frames taken through all filters with NICMOS. The map reveals a resolved 'arc' co-spatial with the optical HST observations. Note that the radio and optical astrometry are independent. The total flux in the arc in the MERLIN map is 900 μJy consistent with the VLA 1.4 GHz flux of 1.18 mJy reported by Lawrence et al (1993), assuming of spectral index ~ 1. However, excluding the longest baselines (> 250 k λ) yields a total flux density of 1.17 mJy. This larger value is likely due to the inclusion of the lens and the counter-image. We appear to have very low S/N detections of the lens and/or counter-image(s) and explore their authenticity below.

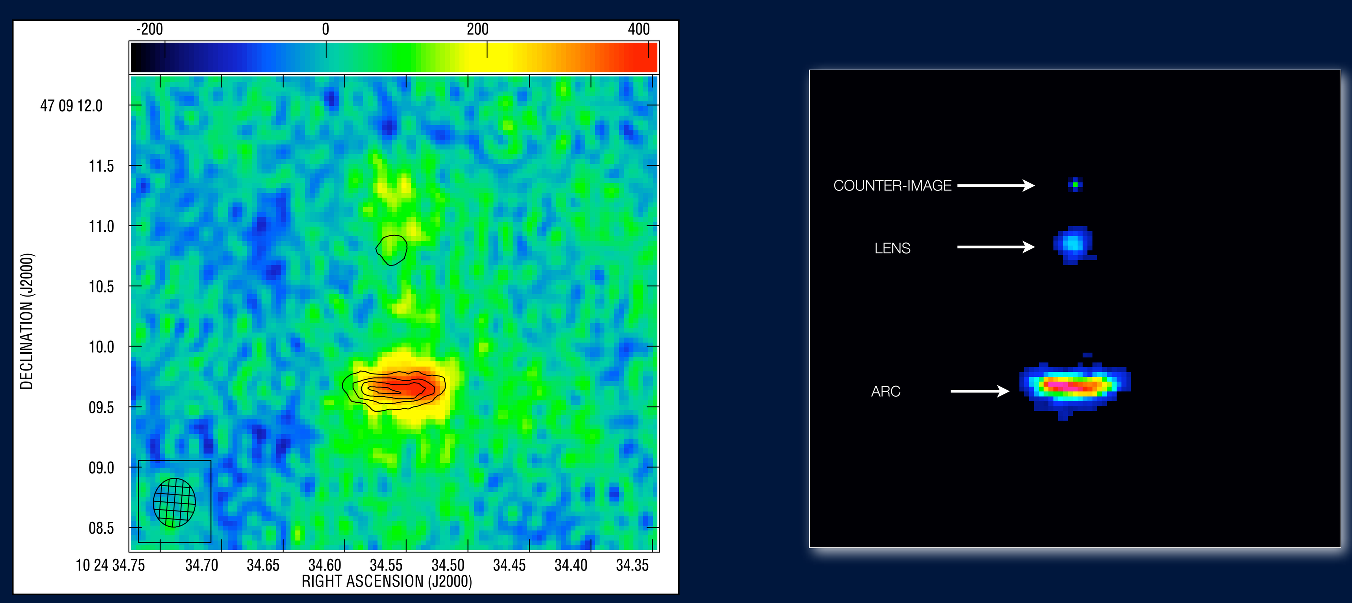

Figure 1: (Left panel) MERLIN *L*-band (colourscale) with HST contours. The HST map is a combination frames taken through all filters with the NICMOS camera. The MERLIN map has a 1-σ noise level of 50 μJy. Note the HST and MERLIN astrometry are entirely independent. Right panel: HST map with counter-image scaled by a factor 10 for illustration.

A SHORT HISTORY

Rowan-Robinson et al. (1991) first discovered IRAS FSC10214+4724 in the IRAS Faint Source Catalogue. It was the highest redshift source detected in the catalogue at the time and appeared to be the most luminous object in the Universe ($L_{bol} \sim 2\times10^{14} M_\odot$). However spectroscopic and morphological arguments purported IRAS FSC10214 to be gravitationally lensed by a foreground galaxy at redshift z ~ 0.9 resulting in a total magnification between 50-100 at restframe optical/UV wavelengths (Broadhurst & Lehar 1995; Serjeant et al, 1995). This was quite spectacularly confirmed by high resolution imaging with the Hubble Space Telescope (Eisenhardt et al, 1996).

Further polarimetric measurements with HST showed the optical light from IRAS FSC10214 light to be 25% polarized (Nguyen et al, 1999), suggesting this was the reflected light of an obscured AGN. X-ray observations with both the Chandra (Alexander et al. 2005) and XMM-Newton (Iwasawa et al, 2009) X-ray space telescopes have made low S/N detections, the fluxes of which are inconsistent with the powerful AGN suggested by [O III]λ5007 emission line strength (Serjeant et al. 1998), leading to the suggestion that this is a Compton thick object. The lower than expected X-ray luminosity could also be explained by differential lensing where the scattering cloud is significantly offset from the AGN. However, Nguyen et al. (1999) limit this distance to a distance range of 40 – 100 pc in the source plane inferred from the smooth polarization position angle variation along the arc at restframe UV wavelengths.

Further puzzling results came from mid-infrared Spitzer spectroscopy which did not reveal strong PAH emission typical of ULIRGs, and silicate emission was detected as opposed to the usual silicate absorption seen towards obscured AGN. These attributes led Teplitz et al. (2006) to conclude IRAS FSC10214 is unlike any ULIRGs or AGN in the local Universe. They proposed that the AGN is preferentially magnified and therefore masks the dominant starburst activity (contrary to Evans et al, 1999, who suggest the opposite based on differential lensing). Clearly the starburst/AGN contributions in IRAS F10214 are yet to be resolved. We are therefore undertaking a programme of high resolution (MERLIN, EVN, VLBA) radio observations in an attempt to reveal the dominant power source of this enigmatic galaxy.

VLA X BAND & SPECTRAL INDEX MAP

X-band observations were performed with the VLA (A-array), with a total of 8 hours on source. The galaxy is resolved and emission at this frequency appears spatially offset from the 1.6 GHz map. Contours of the *X*-band map are shown in the left panel of Fig. 2 along with the resulting spectral index map (right panel) which shows an east-west gradient, reflecting the western position of the *X*-band component. While the most feasible cause is an astrometric offset, the tentative (3-σ) counter-image is consistent with the position (see Fig. 3). If real, the spectral index gradient illustrates the differing radiation mechanisms in IRAS FSC10214+47. This offset would result in differential magnification of the two components, distorting the intrinsic SED.

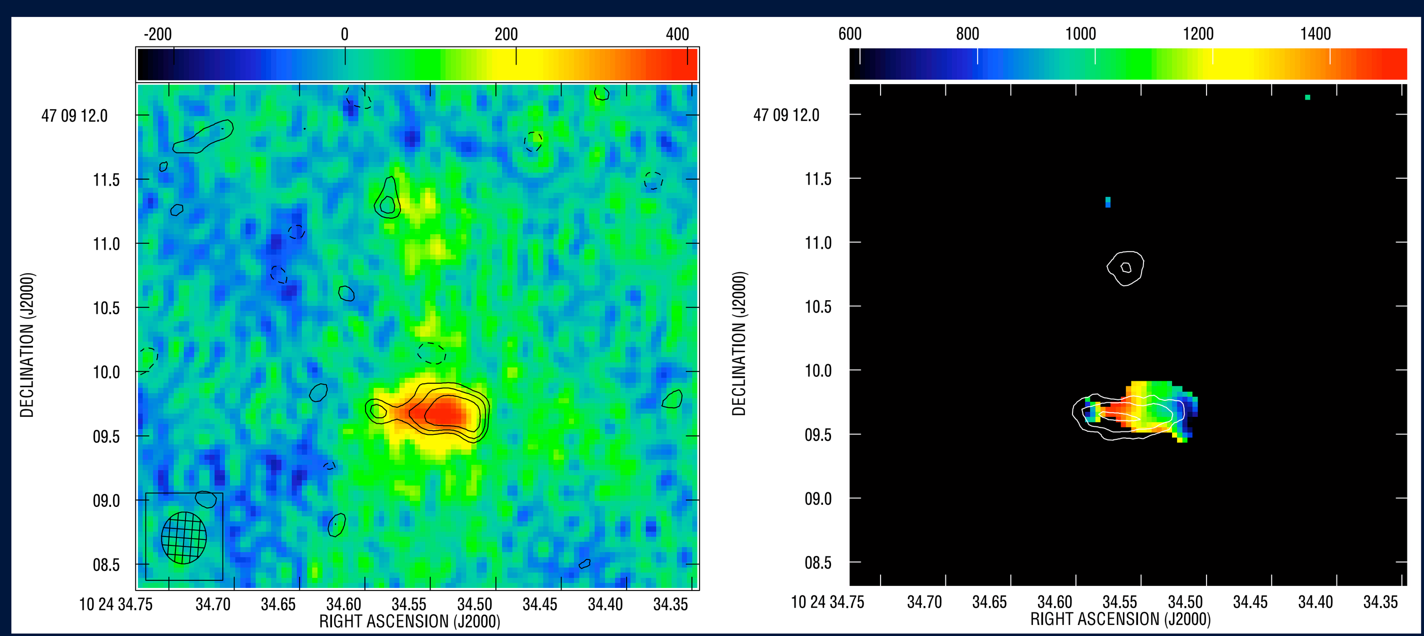

Figure 2: (Left panel) MERLIN *L*-band (colourscale) with overlaid black contours of the VLA *X*-band map. The *X*-band map has a 1-σ noise level of 10 μJy and contour levels are multiples of -2.5, 2.5, 3.5, 5 times the noise. Right panel: Spectral index map of IRAS FSC10214 with HST contours overlaid. The map is derived from the MERLIN *L*-band and VLA *X*-band maps, both clipped at 3-σ. The colourscale is derived with the spectral index convention $S_\upsilon \propto \upsilon^{-\alpha}$ and is scaled by a factor of 1000.

MID-INFRARED TO RADIO SED

The mid-IR through radio spectral energy distribution is shown in Fig. 4. Approximately 99% of the bolometric luminosity is radiated in the infrared. The radio spectral index is relatively steep (α ~ 1) with the appearance of a free-free emission upturn at 5 GHz and 8 GHz, however 15 GHz Ryle observations do not support this. The Spitzer mid-infrared spectrum reveals no strong PAH features expected in ULIRGs. Overplotted on the SED are best fit combinations of a starburst model (Rieke et al, 2009) and a dusty torus model of an obscured quasar (Fritz et al, 2005). As is evident, the fit is very poor, particularly toward the shorter, AGN dominated wavelengths. This is clearly a composite spectrum, however it is complicated further by distortions due to the differential lensing resulting from spatial offsets and the differing physical scales of the emission sources. Our next step is to assign spatial profiles of the AGN and star formation components to 'IRAS FSC10214-like' galaxies, process them through the lensing model and compare the distortions with the observed SED. This will use the Oxford Semi-Analytic Extra-galactic catalogue (SAX).

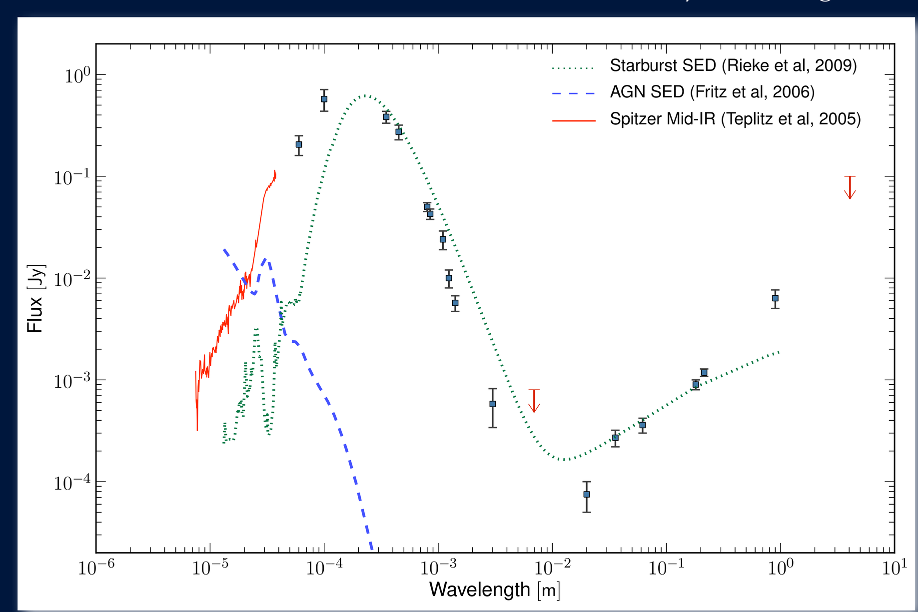

Figure 4: Mid-IR to radio spectral energy distribution of IRAS FSC10214. Model starburst and dusty torus of an obscured quasar are overplotted.

TENTATIVE RADIO COUNTER-IMAGES

Both the 1.6 and 8 GHz maps have tentative counter-image detections. In the 8 GHz case (right panel), the 'counter-image' is offset eastward of the optical counter-image, as predicted by the lens model if the 8 GHz arc is indeed spatially offset from the optical/1.6 GHz as seen in Fig. 2. The scenario of an westward offset, less magnified AGN is consistent with Evans et al (1999) based on their inferred UV and optical magnification factors, however this assertion is degenerate with the level of differential extinction by the lensing galaxy. The relative fluxes ratios of arc-to-counter-image for *L*- and *X*-band are $5.5^{+4}_{-1.5}$ and $6^{+1.8}_{-1.3}$ respectively. This is an approximate indication of the total magnification and therefore proximity to the lens caustic. These values suggest both larger physical scales than the IR (magnification ~10-30) for the *L*-band case and perhaps an AGN with a larger offset from the caustic which represents the locus of maximum magnification.

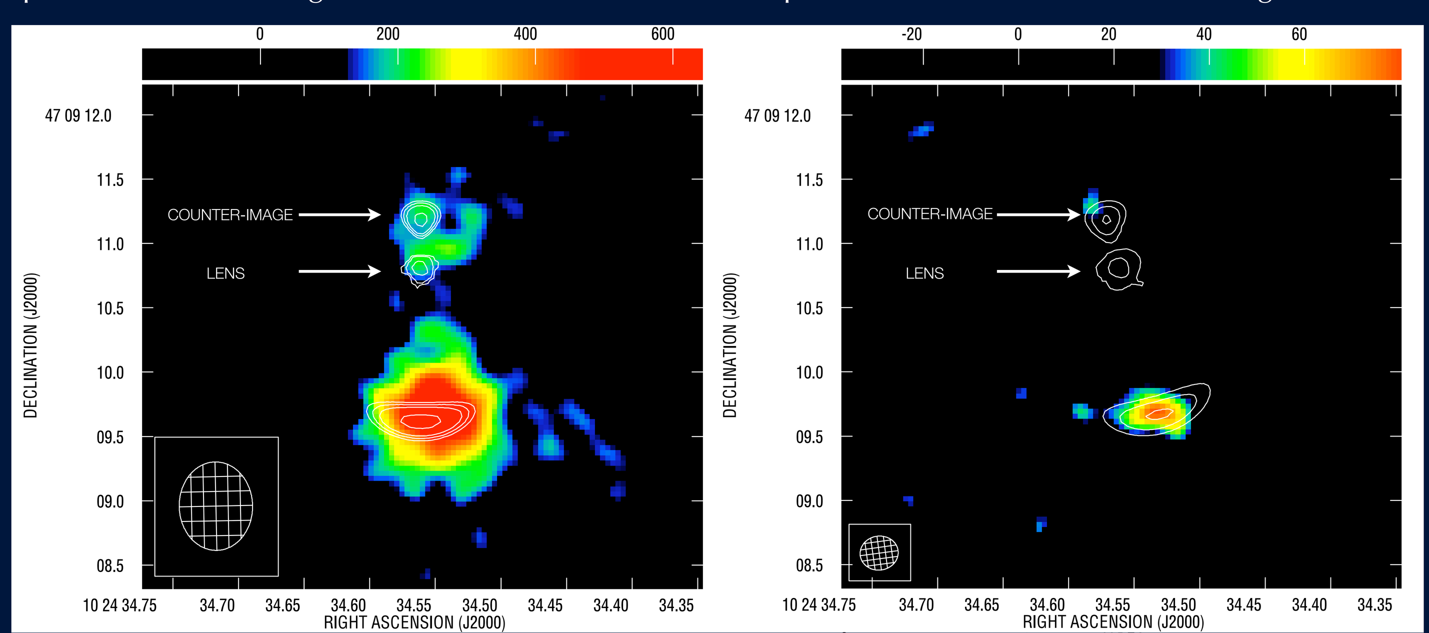

Figure 3: (Left panel) *L*-band map (colourscale) using a uv taper of 700 kλ and clipped at 3σ. Overlaid is the best fit image plane model of the HST map. Right panel: *X*-band map (colourscale) clipped at 3-σ. Overlaid is the best fit image plane model of *X*-band map itself (using a simple pixel-by-pixel least squares minimization). The identical lensing parameters to the HST fit are used, apart from source plane position. The result shows a eastward shifted counter-image, roughly consistent with the tentative counter-image detection at both frequencies.

STARBURST AND AGN COMPONENTS?

It is clear that the relative positions of the multi-wavelength data is key to understanding the underlying morphology and emission mechanisms of this object. Fig. 6 is an enlarged view of the arc with the intention of illustrating the relative positions of the radio emission, molecular gas and rest-frame optical light. The colour map is the MERLIN *L*-band map with an adjusted colourscale to reveal a double peak. All values < 4-σ have been clipped. The flux range within each colour division in this plot is only 0.7-σ, however the `clumping' does provide a suggestion that the double component could be real. The grey contours are restframe *B*-band from HST (NICMOS 1.6 μm). The red cross indicates the quoted centroid of the 1.2 mm, 3 mm, C I and CO (3-2), CO (6-5) from Ao et al (2008), as well as the quoted error of 0.1'' with the Plateau de Bure Interferometer. The white cross is the position of the *X*-band peak with the canonical VLA astrometric error of 0.1''. Higher resolution, multi-band radio data is clearly a key element on gaining further insight into the structure and morphology of this source. We have recently been awarded 22 hours of EVN time to explore this.

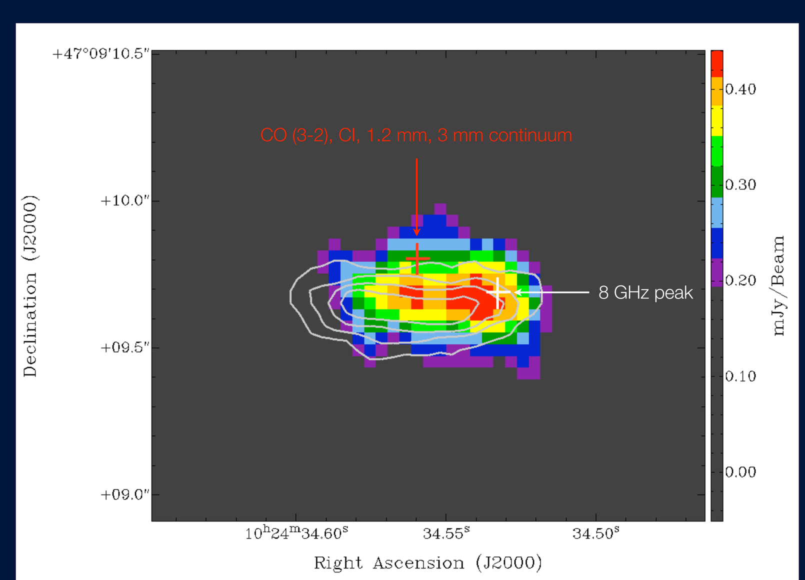

Figure 5: Enlarged *L*-band map of the IRAS 10214 arc with all pixels < 4-σ clipped. Overlaid are grey contours of the HST NICMOS map. The white cross indicates the peak of the 8 GHz map. The red cross indicates the centroid of the CO (3-2), C I, 1.2 mm and 3~mm continuum (Ao et al, 2008). Both crosses indicate the canonical 0.1″ absolute astrometric uncertainty of the VLA and PdBI.

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