A MULTI-WAVELENGTH VIEW OF THE ISM IN NEARBY GALAXIES

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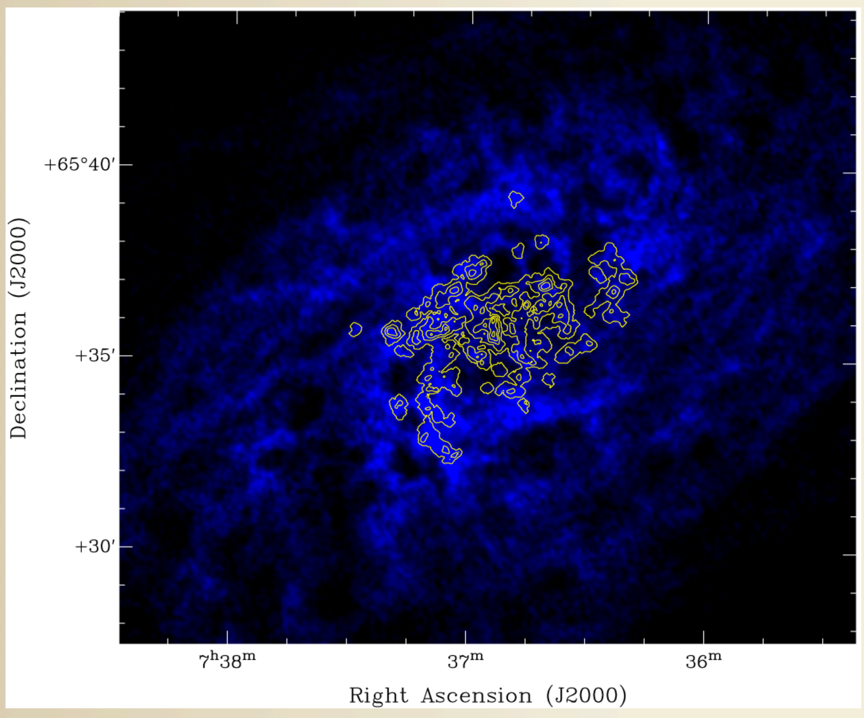

Figure 1. HI integrated map with CO contours overlaid

Abstract

We are developing an objective, automated method to compare multi-wavelength images based on 2–D pixel-by-pixel cross-correlations. We introduce a measure for the degree of correlation, C_{coef}, which takes values from 1 (perfect correlation) to −1 (perfect anti-correlation). This we subsequently applied to NGC 2403, as a pilot project. We produce spatially resolved cross-correlation maps, on scales of 250 pc to 1000 pc and radial profiles of the cross-correlation coefficients. We find that i) all dust tracers, 8μm–70μm, are well correlated (C_{coef} > 0.7) at all scales; ii) all the star formation tracers are well correlated at scales larger than 500 pc (C_{coef} > 0.6); iii) at 250 pc scale, FUV correlates poorly (C_{coef} ~ 0.3) with any dust tracer, a direct consequence of the absorption of FUV photons by dust; and iv) neutral atomic hydrogen is tightly correlated with the 8μm emission (C_{coef} ~ 0.6), illustrating the fact that HI is mixed with PAH's.

Introduction

The characterization of the ISM relies upon examining its various components as seen by different tracers. In order to see how each component relates to others, it is important to analyse each tracer in detail. With the deployment of *Spitzer* and the Galaxy Evolution Explorer (*GALEX*) high resolution observations of samples of nearby galaxies are for the first time available at MIR and FUV wavelengths and a comparison between the various components of the ISM is now possible. However, this comparison is challenging; qualitatively it can be done by visually describing and comparing maps atdifferent wavelengths (e.g., Fig. 2). However, this method carries an unavoidable degree of subjectivity and is limited in terms of scale and detail.

A more robust way of comparing maps is to do so in a quantitative way and a few such attempts have been made. Of these the most widely used is wavelet analysis which allows the isolation of structures, such as spiral arms, filaments and clumps, from a map. This method characterizes a map based on features on different scales but with any information on the physical location of these features lost. We present the development of a 2-D cross-correlation method to compare multi-wavelength maps and give some first results from the application of this method to the nearby galaxy NGC 2403. Specifically, we attempt to examine the similarities and differences in the distribution of certain ISM components of this galaxy. Based on the study of HI holes (Bagetakos et al. 2011) we focus our analysis on three constituents of the ISM: gas, dust, and massive stars.

Observations

In this pilot study we focus on the ISM of a single galaxy, NGC 2403, for which we have access to observations covering a large part of the EM spectrum. These include HI from THINGS (Walter et al. 2008), CO(2-1) from HERACLES (Leroy et al. 2009), 8μm, 24μm, and 70μm from SINGS (Kennicutt et al. 2003), Hα from the SINGS Data Release 4 and FUV from the NGS (Gil de Paz et al. 2007). Since we will be looking at individual structures, we selected NGC 2403 for its large number of HI holes detected (Bagetakos et al. 2011). An area of particular interest is how structures in the ISM as traced at different wavelengths relate to areas of star formation. Following Leroy et al. (2008) we created a star formation surface density map. A visual comparison of some of these maps is presented in Fig. 2.

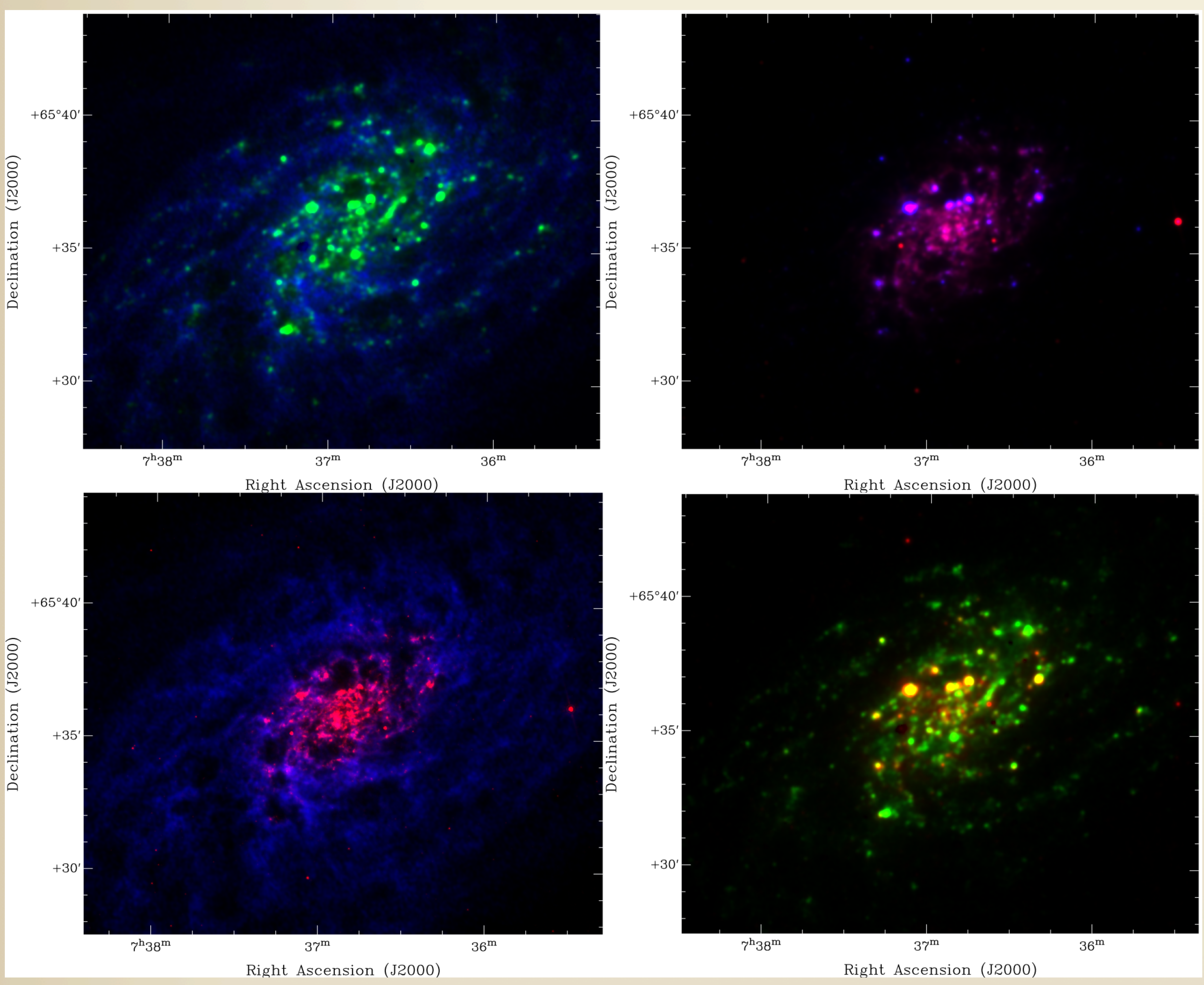

Figure 2. A visual comparison of various tracers in NGC 2403. Top left: HI (blue) - FUV (green);Top right: 8μm (red) - 24μm (blue); Bottom left: HI (blue) - 8μm (red); Bottom right: FUV (green) - 24μm (red). The quantified correlation of these pairs is illustrated in Fig. 4.

The cross-correlation method

In order to quantify the above relations we proceeded to develop a method of comparing multi-wavelength images based on 2-D pixel-by-pixel cross-correlations. Each image was divided into sub-images (e.g., 15" by 15" in size). Each sub-image was cross-correlated with its counterpart in a map at a different wavelength. This method was then applied to all the aforementioned images, excluding CO, after convolving every image to the same spatial resolution (8"). The result of the cross-correlation is quantified by the cross-correlation coefficient C_{coef} which takes values from 1 (perfect correlation) to −1 (perfect anti-correlation). This results in a map of the cross-correlation between images at different wavelengths at 15" scale. This was repeated at 30" and 60" scales. We found that C_{coef} varies significantly at scales less than ~ 200" (3.1 kpc) reflecting structural differences in the various maps (Fig. 3). The C_{coef} value was also found to drop significantly when comparing sub-images centred at areas outside the R25 radius due to low signal-to-noise ratios in most of the maps. Consequently, we decided to compare sub-images at three different scales (15", 30" and 60") located within R_{25} . Here "scale" means the area over which the cross-correlation is evaluated.

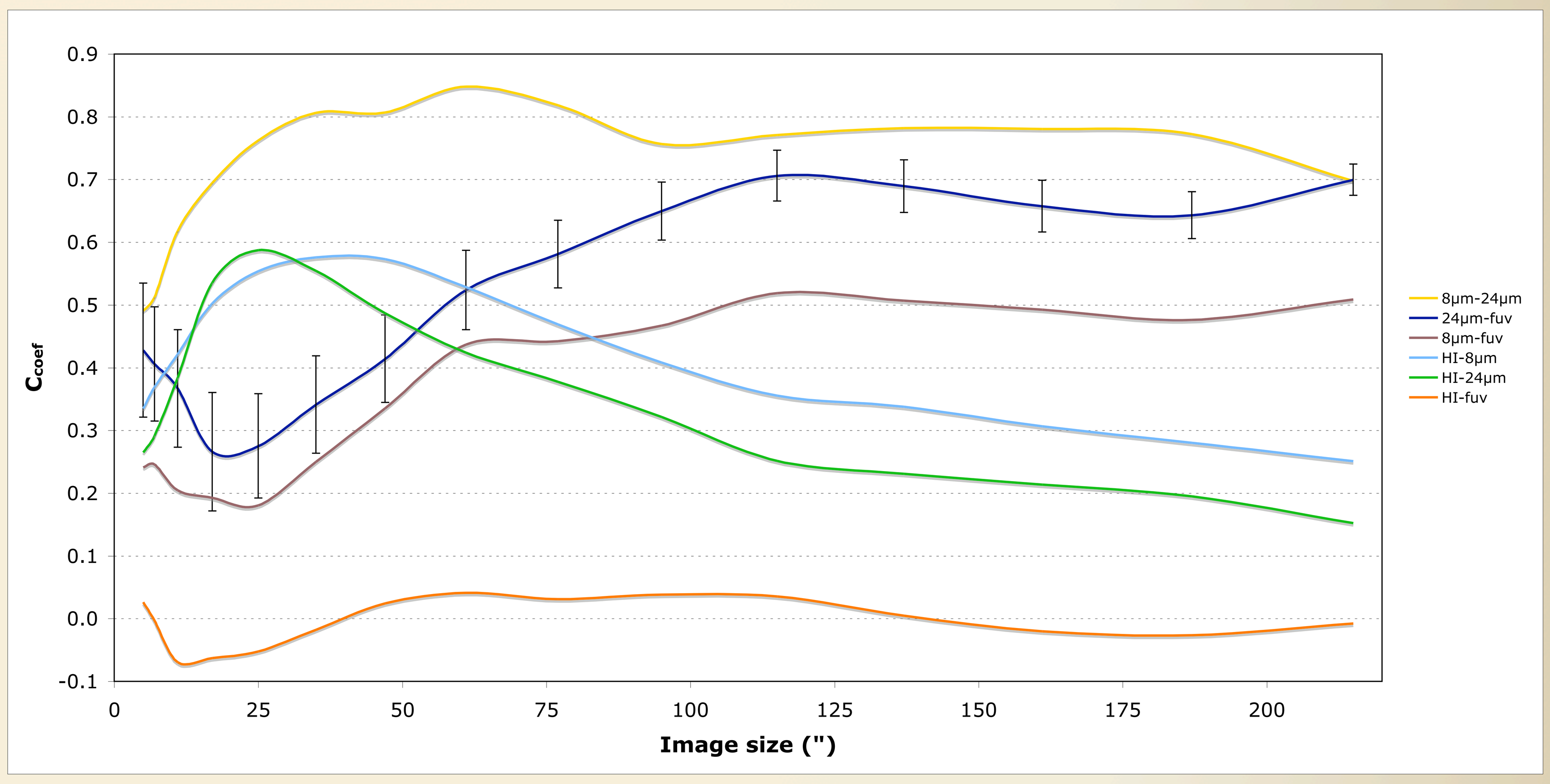

Figure 3. The mean C_{coef} over the central areas as a function of scale. The error bars on the 24μm-FUV case represent the typical uncertainty.

First results

Comparing every image with every other image we established the following key results:

- the dust tracers are well correlated (C_{coef} > 0.7) at all scales with the exception of 8μm-70μm at 15" (C_{coef} = 0.5);
- the star formation tracers are well linked at 30" and 60" as expected (C_{coef} > 0.6). However the correlations drop at the 15" scale where there is an offset between current and recent star formation;
- with respect to the relations between star formation and dust tracers we found that most are well matched (C_{coef} > 0.7) as dust grains are heated by radiation in star forming regions. At the 15" scale FUV correlates poorly (C_{coef} ~ 0.3) with the dust tracers, a direct consequence of the absorption of FUV photons by dust;
- the gas component is well correlated with the 8μm emission (C_{coef} ~ 0.6) illustrating the fact that HI is mixed with PAHs;
- the HI map shows some correlation with the SF map (C_{coef} ~ 0.4); surprisingly FUV and HI emission were found to be completely uncorrelated (C_{coef} ~ 0).

We are now in a position to examine the correlation (or lack of) of tracers with respect to the position in a galaxy as Fig. 4 illustrates and therefore relate these to areas of star formation, spiral arms, etc.

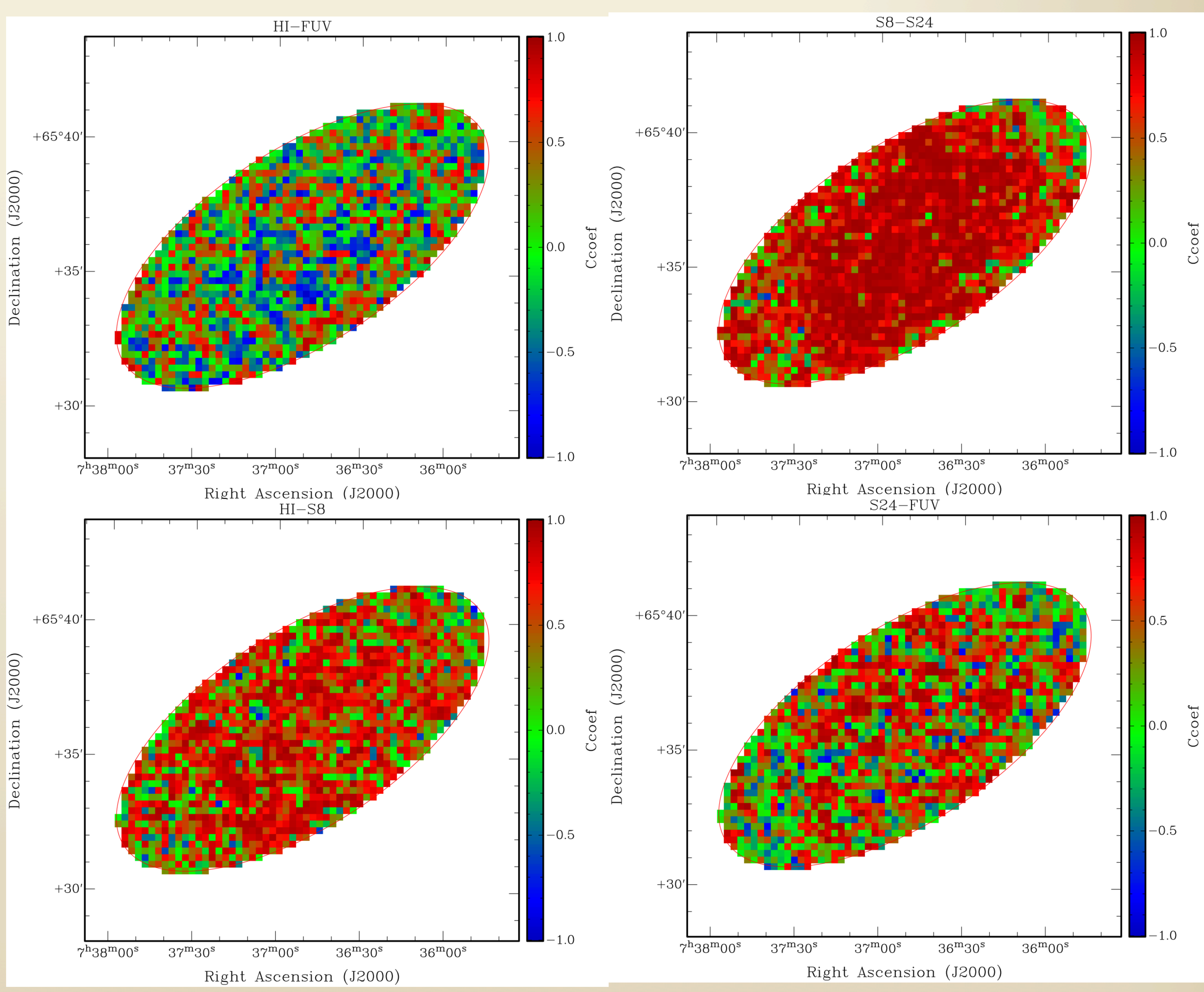

Figure 4. The C_{coef} as a function of position in the galaxy for the HI-8μm (top left), 8μm - 24μm (top right), HI - 8μm (bottom left) and FUV - 24μm (bottom right) cases. The size of each box is 15" by 15" and the ellipse corresponds to R_{25}.

References

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