Dust, Gas, and Star Formation in Andromeda: The HELGA, HASHTAG and PPMAP Perspective

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1 ABSTRACT

Studies of Andromeda (M31) are important as it is the only other large spiral in the Local Group, and unlike the Milky Way we can obtain a complete census of all star formation, gas and dust in the galaxy. In this poster I present new work taking observations from our *Herschel* survey (HELGA), and applying a new SED fitting technique (PPMAP). PPMAP gives improved resolution dust maps and measures the amount of dust for a range of temperatures along the line of sight. The PPMAP maps confirm our previous result that physical properties of dust vary within a galaxy, and also solves problems found by previous studies that found a systematic offset in the amount of dust derived from optical extinction versus dust emission. We are now building on the *Herschel* legacy with a survey on the JCMT at longer submillimetre wavelengths. HASHTAG is a new 280 hour project which will observe the whole of Andromeda at 450 and 850μm and selected regions in CO(J=3-2). The combination of *Herschel*, HASHTAG, and PPMAP will produce maps of the dust in Andromeda with ~25 pc resolution, less than the size of a giant molecular cloud. We these maps we will be able to answer questions, such as how does the Schmidt-Kennicutt law arise from individual giant molecular clouds.

2 Herschel Exploitation of Local Galaxy Andromeda (HELGA)

The HELGA survey was an open-time project with *Herschel* to produce the most complete far-infrared survey of Andromeda. The survey covered the entire HI disk with a $5.5° \times 2.5°$ field and observes with both PACS and SPIRE instruments at 100, 160, 250, 350 and 500μm. The combination of the proximity of M31 and the large 3.5m mirror of *Herschel* means we resolve physical scales of ~48 pc at 100μm, to ~150 pc at 500μm.

The HELGA survey has led to many results including:

- Detect new dust structures, out to ~31 kpc.
- Variations in the properties of dust within a galaxy.
- To fit structure requires 2 rings (10.3, 15.5 kpc) + 2 spirals arms
- 91% of dust is heated by evolved stellar population

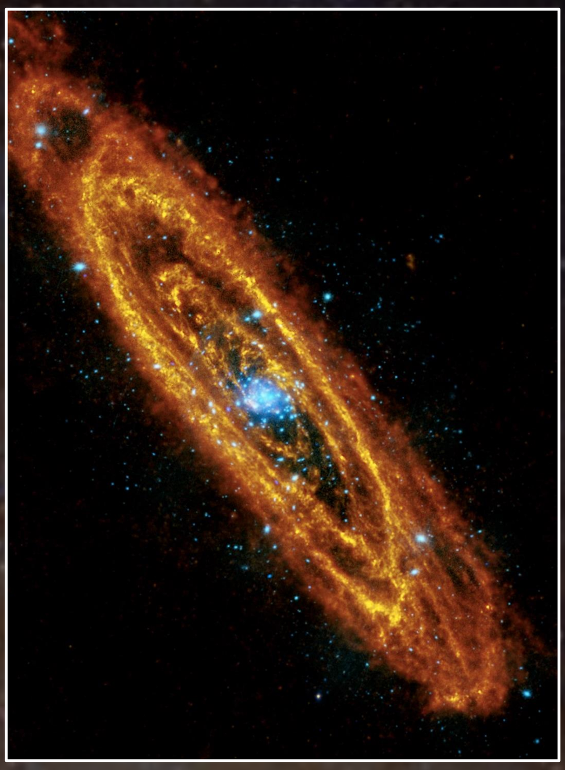


Figure 1
The HELGA 250μm image (heat) and XMM-Newton X-ray (blue). Credit ESA

3 HARP and SCUBA-2 High Resolution Terahertz Andromeda Galaxy Survey (HASHTAG)

HASHTAG

To make significant progress over the *Herschel* studies, both higher resolution and longer wavelengths are required. The HASHTAG survey is a new 280 hour large program on the JCMT to observe the entirety of M31 at 450 and 850μm, and selected regions in CO(J=3-2). Our survey will make it possible, to investigate dust, the ISM, and star formation, from the scale of a galaxy down to sub-GMC scales. With a resolution of ~25 pc, we will be able to study M31 with fives times better resolution than previous dust studies. Ground based sub-mm observations normally struggle to recover large-scale structure, to mitigate for this we have developed tools to combine our ground-based data with lower-resolution space-based data. The figure below shows the results of our pilot SCUBA-2 observations.

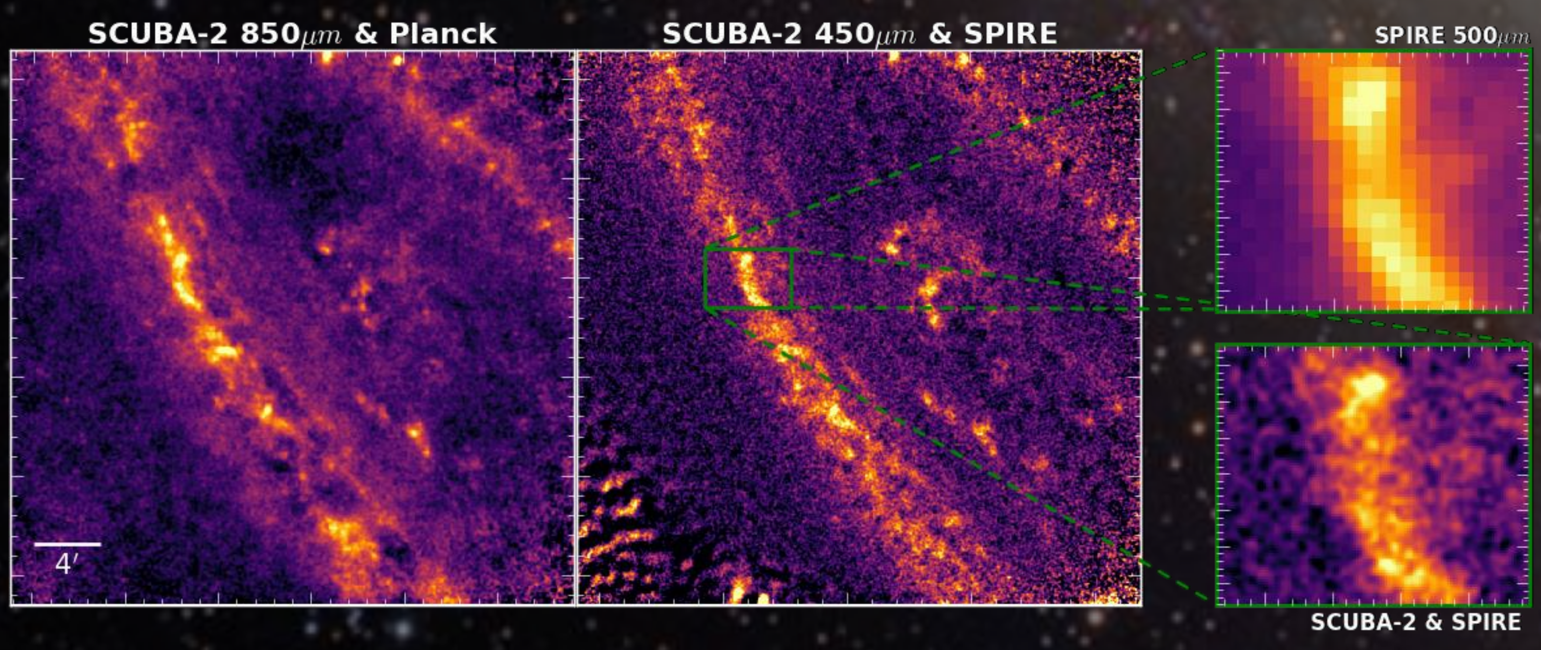


Figure 2: The 850μm (left) from our pilot program which observed a 30′ region of M31. For both bands, we use data from either *Planck* or SPIRE to add in large scale structure.

4 PPMAP

Traditionally the standard method of fitting spectral energy distributions (SEDs), involves convolving all the images to a common resolution and assuming a single dust temperature. PPMAP (Marsh et al. 2015), is a Bayesian procedure that uses dust continuum images, and their associated point spread functions, to create resolution-enhanced maps of column density in bins of dust temperature and dust emissivity index (β). The only assumptions made by PPMAP are that the dust is in thermal equilibrium and that the emission is optically thin. An example of PPMAP applied to *Herschel* data is shown in the figure below.

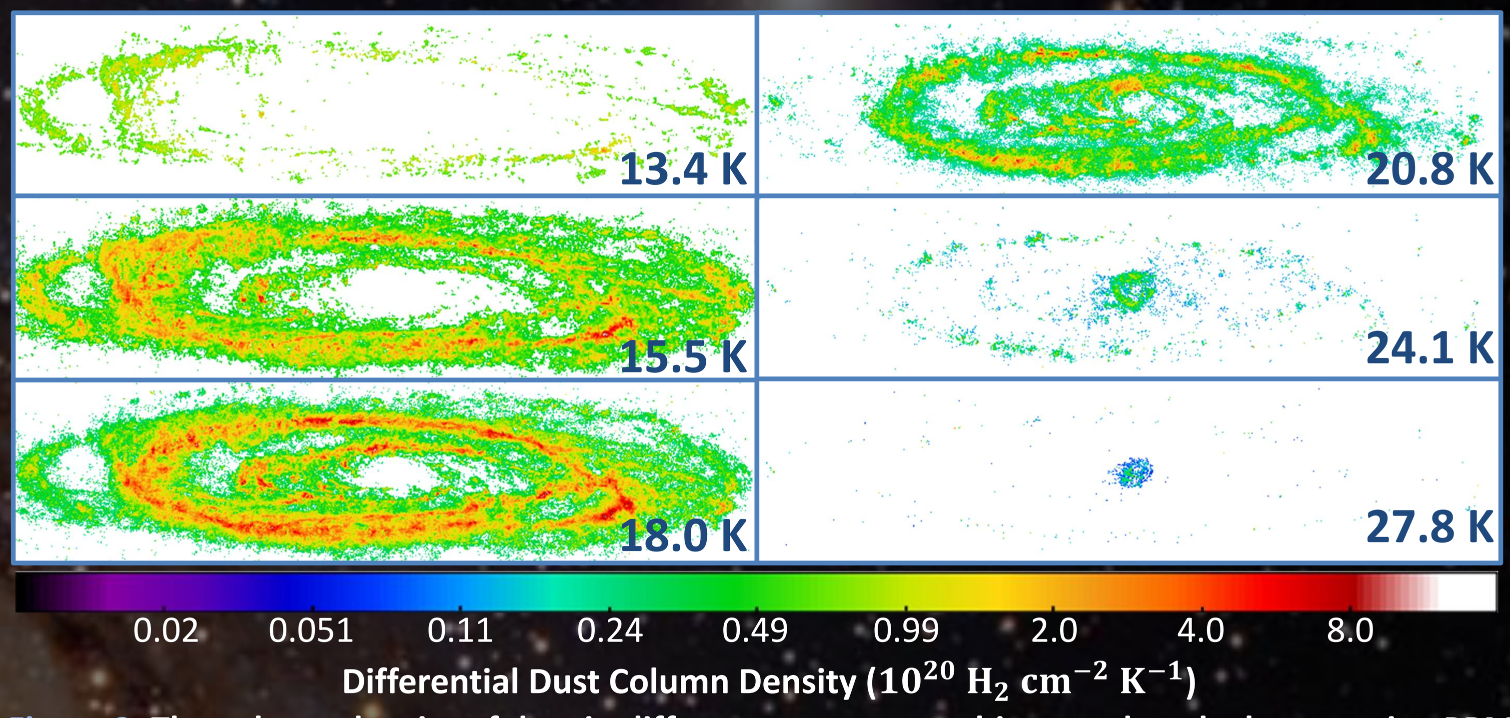


Figure 3: The column density of dust in different temperature bins, produced when running PPMAP on the *Herschel* images.

5 Dust Analysis of Andromeda

In Smith at al. (2012) we discovered that the properties of dust varied radially within Andromeda, suggesting either the grain size, composition, or growth of mantles varied within the galaxy. With PPMAP run on the just the HELGA data we have confirmed the changes in the dust emissivity index. With the extra resolution and wavelength coverage that will be possible with the complete HASHTAG survey, we hope to investigate what are the exact origins of the changes in the dust.

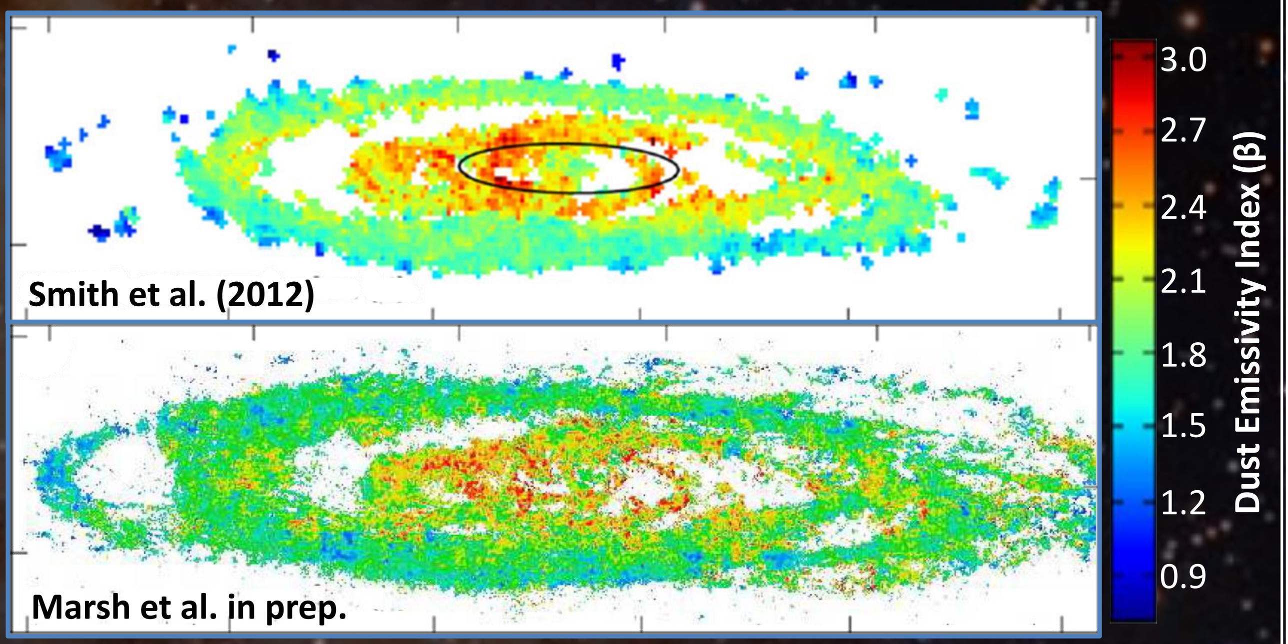


Figure 4
Dust emissivity index maps for M31. The top panel shows the traditional approach from Smith et al. (2012) where the image is convolved to a common resolution. The bottom panel shows the result from the new PPMAP processing on the *Herschel* images (Marsh et al. in prep.).

The Panchromatic Hubble Andromeda Survey (PHAT), has covered approximately a third of Andromeda with *Hubble*. Recently Dalcanton et al. (2015) found that the dust surface density was a factor of ~2.5 lower when estimated from dust extinction than using dust emission (using the Draine et al. model). With PPMAP we can make this comparison at far higher resolution, and without assuming a distribution in grain temperature. We find a much better agreement between the two, although some regions do show significant differences.

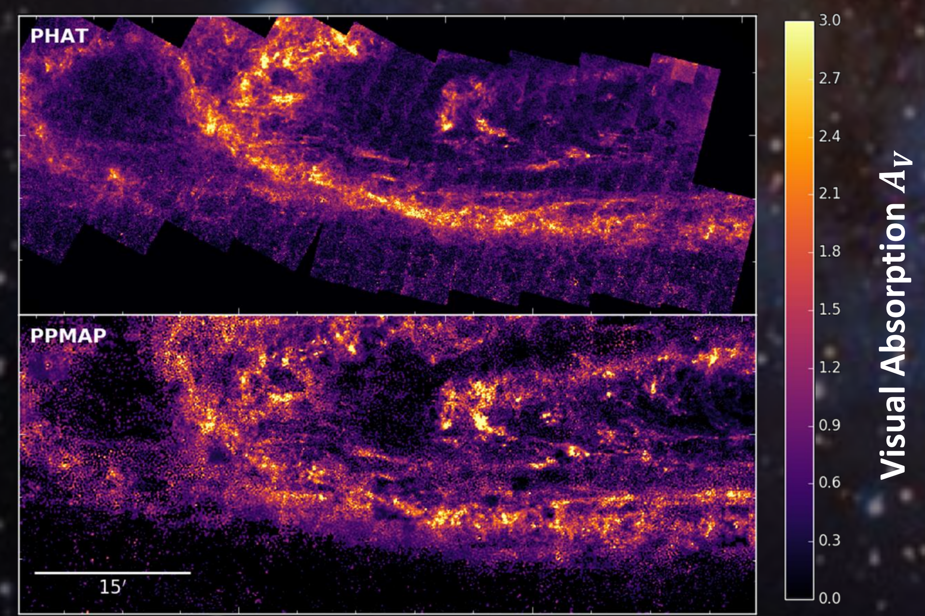
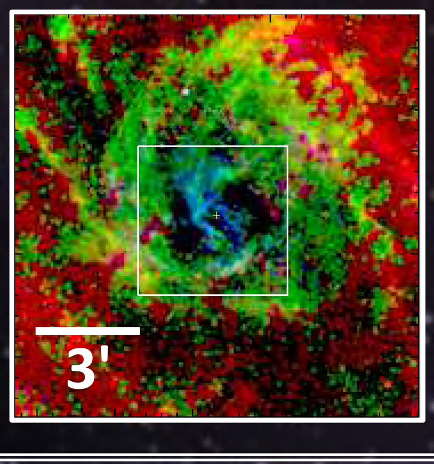


Figure 5
The visual absorption found from optical *Hubble* observations (top), and those obtained from far-infrared dust emission measurements using PPMAP (bottom).

Figure 6
A three colour composite image of the central 12′ of M31. Red represents dust between 10-18 K, green between 20.8-27.8 K and blue is between 32.2-50 K



A prominent feature in our dust temperature maps is the nuclear region, which contains a ~500 pc bar that has been previously observed in Hα, and is offset significantly from that of the large-scale bar. The bar contains our hottest dust in the galaxy with temperatures in excess of 30 K. Our analysis combined with 2MASS and radial velocity data suggests this is a gravitationally induced bar, which may represent a channel for accretion towards the nucleus.

6 Star Formation Laws in Andromeda

With the HELGA *Herschel* data, Ford et al. (2013) investigated the Schmidt-Kennicutt law ($\Sigma_{SFR} \propto \Sigma_{gas}{}^{N}$), both globally and regionally within a galaxy. Similar to results from the HERACLES team on nearby galaxies, it was found that the best correlation between gas and star formation was found when only considering molecular gas (as traced by CO). Unlike HERACLES who found $N \approx 1$, for M31 the relation was found to sub-linear (i.e., $N < 1$). Similar work on M33 by Williams et al. (submitted), suggest that the measured relation depends on the scale you measure. By using PPMAP and data from HASHTAG, we will be able to resolve individual giant molecular clouds and see how the Schmidt-Kennicutt law arises from the individual cloud properties.

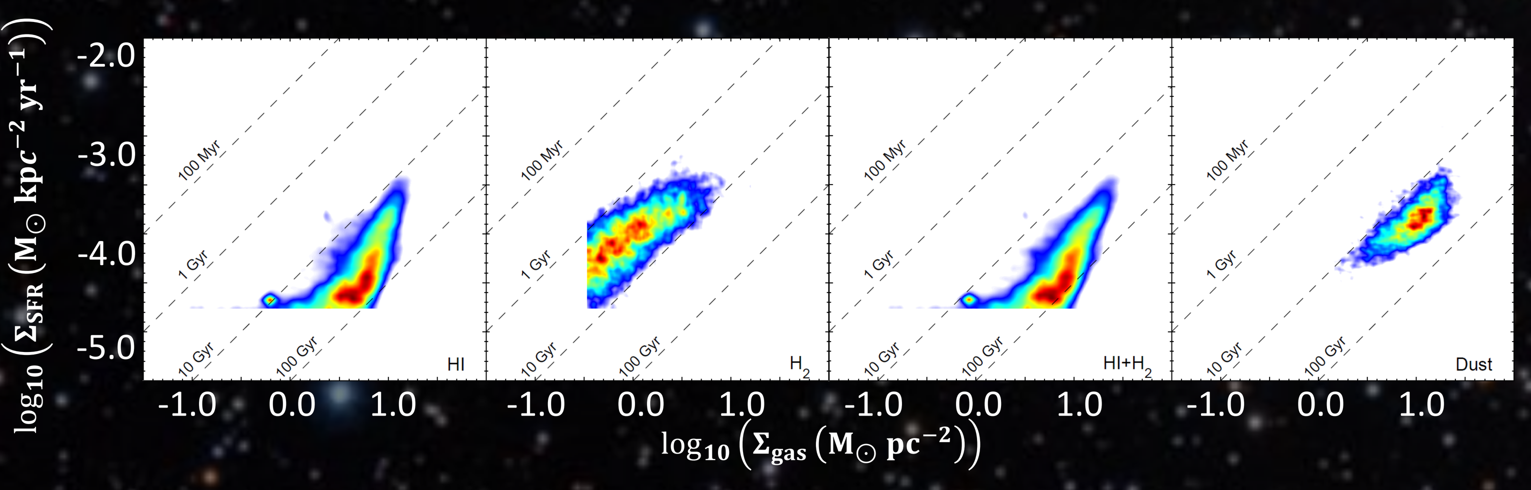


Figure 7 : Star formation rate surface density against gas surface density in M31. The star formation rate is traced using a combination of FUV + 24μm, while the gas surface density, from left to right, is traced by HI, H_2, total gas (HI + H2), and dust. The dashed lines show are constant gas depletion times.

7 Conclusion / Future Work

The *Herschel* data has already taught us a lot about the relationship between gas, dust and star formation within galaxies. With HASHTAG data, and advances in SED fitting techniques (e.g., PPMAP), we will be able to map dust in M31 with a resolution of 25pc, revolutionising our view of the ISM.

REFERENCES

Dalcanton et al., 2015, ApJ, 814, 3
Marsh et al., 2015, MNRAS, 454, 4282
Smith et al., 2012, ApJ, 756, 40
Ford et al., 2013, ApJ 269, 55
Marsh et al., in prep.
Williams et al., submitted to MNRAS

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