Dust, Gas and Star Formation in Andromeda

Matthew Smith
Gas as a tracer has been suggested since Hilderbrand (1983)

Found promising with Herschel e.g., Eales et al. (2010/12), Sandstrom et al. (2014), need to account for the metallicity

Becoming more prominent with ALMA continuum measurements of high-z galaxies being efficient (Scoville 2016).

For Early-Types ETGs are more easily detected with Herschel than gas tracers (Smith et al. 2012, Amblard et al. 2014)

Dust Seems Ubiquitous

- Dust extends all the way into the galaxies outskirts
- Holwerda (2009) detected dust to $1.5 R_{25}$ via occulting pair
- Traced in emission with IRAS (Nelson et al. 1998), and Herschel (Smith et al. 2016)
- Possible (?) explanation of Menard et al. results if assume galaxy clustering

Holwerda (2009)

Smith et al. (2016)
Dust Has Its Problems

- Dust opacities are uncertain
- Exact size distribution, composition… are uncertain
- How reliably can we know gas to dust ratio (metallicity, morphology, etc…)

To solve these problems – two local potential solutions:
  - Need samples that cover a range of all galaxy properties (e.g. JINGLE – Isabella's talk yesterday)
  - High-resolution studies of objects that cover a range of objects
Herschel Exploitation of Local Galaxy Andromeda (HELGA)

- All 6 bands (include alternative Krauss project)
- Observations cover entire HI disc
- Fritz et al. (2012) survey paper – looking for dust associated with HI
- From nearby galaxies know dust extends to $2 \times R_{25}$ (Smith et al. 2016)
HELGA II: SED Fitting (Smith et al. 2012)

Processing:
• Convolve and rebin all bands
• 140pc resolution
• Restrict to all 5 fluxes $> 5\sigma$
• Take into account all correlated uncertainties
• 4000 independent pixels

Fit 1 modified blackbody model

Find a need for a variable $\beta$

Method is not optimal as information is thrown away

Both HELGA II (Smith 2012) and Groves (2012) found dust in the centre is heated by the stars in the bulge

HELGA VII (Viaene 2016), from radiative transfer 91% dust heated from bulge, extending out to the 10kpc ring.
Beta Results

- Change in $\beta$ around 3.1 kpc
- High values not multiple-T
- Not reliant one point – statistics
- $\beta = \sim 1.8$ in main ring is in good agreement with Planck early results
- Results confirmed with independent Andromeda survey (Draine et al. 2014), also Planck sees similar variation (Planck Col/Peel et al. 2014)
- Differences in $\beta$ could be caused by changes in the grain size, icy mantles, or freshly formed grains.
- Problem is no obvious correlation with say properties of molecular gas to provide shielding etc…
Variations of $\beta$ in Other Galaxies

Many studies have seen variations in other objects:

- **M33**
  - Tabatabaei et al. 2013

- **KINGFISH 20 galaxies (NGC0628)**
  - Kirkpatrick et al. 2014

- **LMC Complex N11**
  - Galametz et al. 2015
Planck – Dark Gas (2011)

- \[ \tau = \left( \frac{\tau_d}{N_H} \right)^{ref} \cdot N_H^{obs} + \text{con} \]
- Dark gas \(\rightarrow\) 28\% of atomic gas, 118\% of \(\text{H}_2\)
- Average X-factor 2.54
Is there Dark Gas in Andromeda?

- Adjusted for radial metallicity gradient
- No region dominated by molecular gas
- Line-if-sight averaging
- Best fit X-factor
  \[(2.0 \pm 0.4) \times 10^{20} \text{ cm}^{-2} [\text{K km/s}]\]
- HELGA V (Mattson et al. 2014) suggests growth in ISM important from dust-to-metals and gas-to-dust ratio
HELGA IV: Viaene et al. (2014)

- MAGPHYS panchromatic fits to entire image
- Individual regions fit on global dust scaling relations (Cortese et al.)
Star-Formation Law in Galaxies

- Ultimate goal, to understand the key physical drivers and regulators of star-formation, and their defining physical relationships
- Andromeda (& soon M33) are unique as can get detailed SFH and current SFR as resolve individual stars with Hubble
- Breaks down in ULIRGS, and low metallicities
- For M33 (Williams, T et al. 18) show how $N$ varies when measuring on different scales

**Global Scale**

Kennicutt (multiple refs)  Bigiel et al. 2008 (THINGS)  Ford et al. 2013

**Nearby Galaxies**

Andromeda – HELGA III
How can we make more progress?

► At 500µm the physical resolution is 140pc – not good enough compared to other tracers

► To make significant progress we need to:

1. Improve SED fitting techniques to make best use of data

2. Improve observations, with higher-resolution and greater wavelength coverage
PPMAP works on the raw-images, i.e., preserves all the information

Instead of fitting an unphysical one temperature or assuming a T-distribution, PPMAP assumes a discrete range of temperatures

Designed originally to work on galactic plane

Generates x, y, T hypercube

Uses Bayesian point source process algorithm

Inputs:
- Dust continuum images
- PSFs
- Grids of possible values of T (i.e., prior distribution)

Assumption – all has to be optically thin.

Need High S/N data
PPMAP of Andromeda

- Use 12 bins in Temperature spread logarithmically spaced between 10-50K
- With Herschel data alone we can recover 30pc scales
- Whitworth et al. submitted, Marsh et al. (2018)
PPMAP

temperatures

- $T = 10.0 \text{ K}$
- $T = 11.6 \text{ K}$
- $T = 13.4 \text{ K}$
- $T = 15.5 \text{ K}$
- $T = 18.0 \text{ K}$
- $T = 20.8 \text{ K}$
- $T = 24.1 \text{ K}$
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Smith et al. (2012)
What about $\beta$?

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PPMAP – Mass-weighted $\beta$
PHAT vs PPMAP (Whitworth et al. submitted)

► Have a good overall agreement between optical extinction and dust emission
PPMAP – The future

- Run on a large reference sample (HRS/KINGFISH/Dustpedia etc…)

- Planning on rolling out PPMAP to M33 (where we already have deep SCUBA-2, Williams et al. 2018)
HARP and SCUBA-2 HI-resolution Terahertz Andromeda Galaxy survey (HASHTAG)

- Large program with the JCMT (I’m the UK PI) – 275 hr
- Idea is to get deep SCUBA-2 images for the entirety of Andromeda
- CO\((J=3-2)\) is a big contaminant between 10-30%. Proposed 60 square arcminutes to calibrate contamination.
- 25pc resolution, expecting ~2000 clouds with > 10^3 M⊙

But what about problems SCUBA-2 and extended structure?
SCUBA-2 uses filtering in the DR, set too light instrumental noise dominates, too harsh remove emission

Had the idea to borrow from radio and use Planck 870µm to recover large scales so can use stronger filter
At 450µm we use the SPIRE 500µm emission to recover the large scale emission.
HASHTAG – some science goals

- Properties of dust and what do they depend on
- Testing the origins of $\beta - T$ relation
- What is heating the dust
- Measure the variations in gas-to-dust and X-factor
- Investigate the origins of the KS-law
- SF in M51 found to be in spurs off the spiral alms. In M31 we can test morphological relationship between SF & ISM, by using OB star in PHAT and other star formation indicators
- Sub-millimetre transients
When can you trust energy balance?

► Dust energy balance seems to work on 1.5kpc scales
► Agrees with other works that suggest 1kpc

► Tom Williams (Williams et al. submitted)
► Performed SKIRT radiative transfer on M33