HASHTAG, JINGLE and Nearby Galaxy Science

Matthew Smith

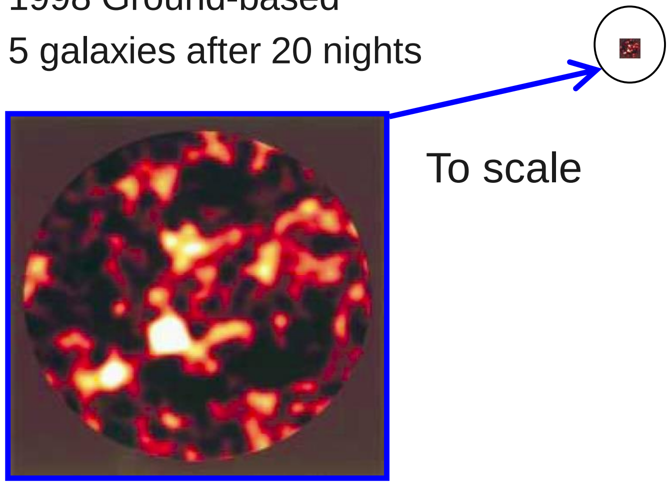
Dusting the Universe 2019

Overview – Continuum Talk

- 20 minutes too short to talk about all JCMT nearby galaxy science
- Will talk about some very selected dust topics/problems
- HASHTAG
- JINGLE (also see Yang Gao talk)
- Potential future projects

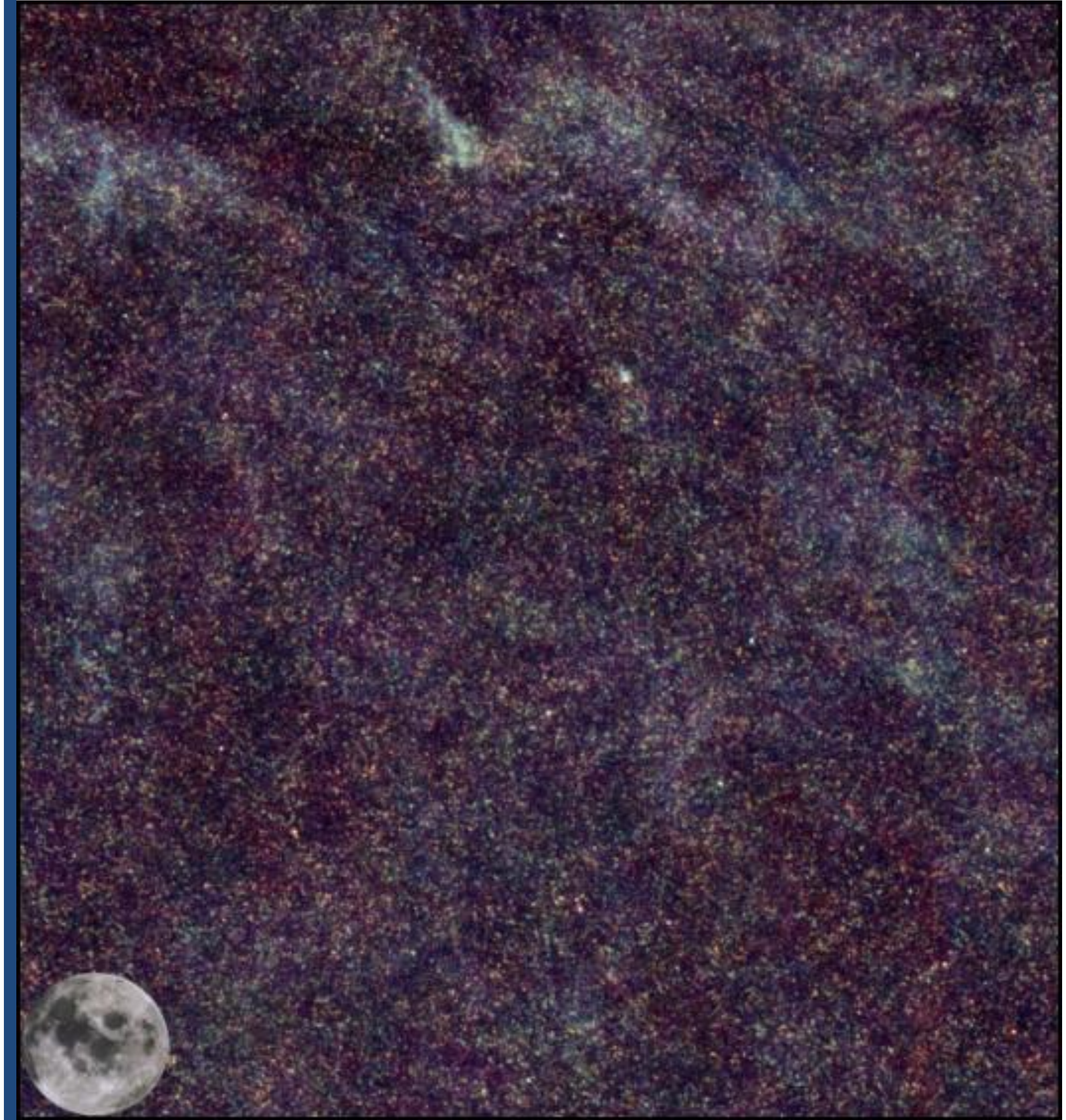
Dust as a Tracer

1998 Ground-based
5 galaxies after 20 nights



To scale

- 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)



16 out of 660 sq. degrees

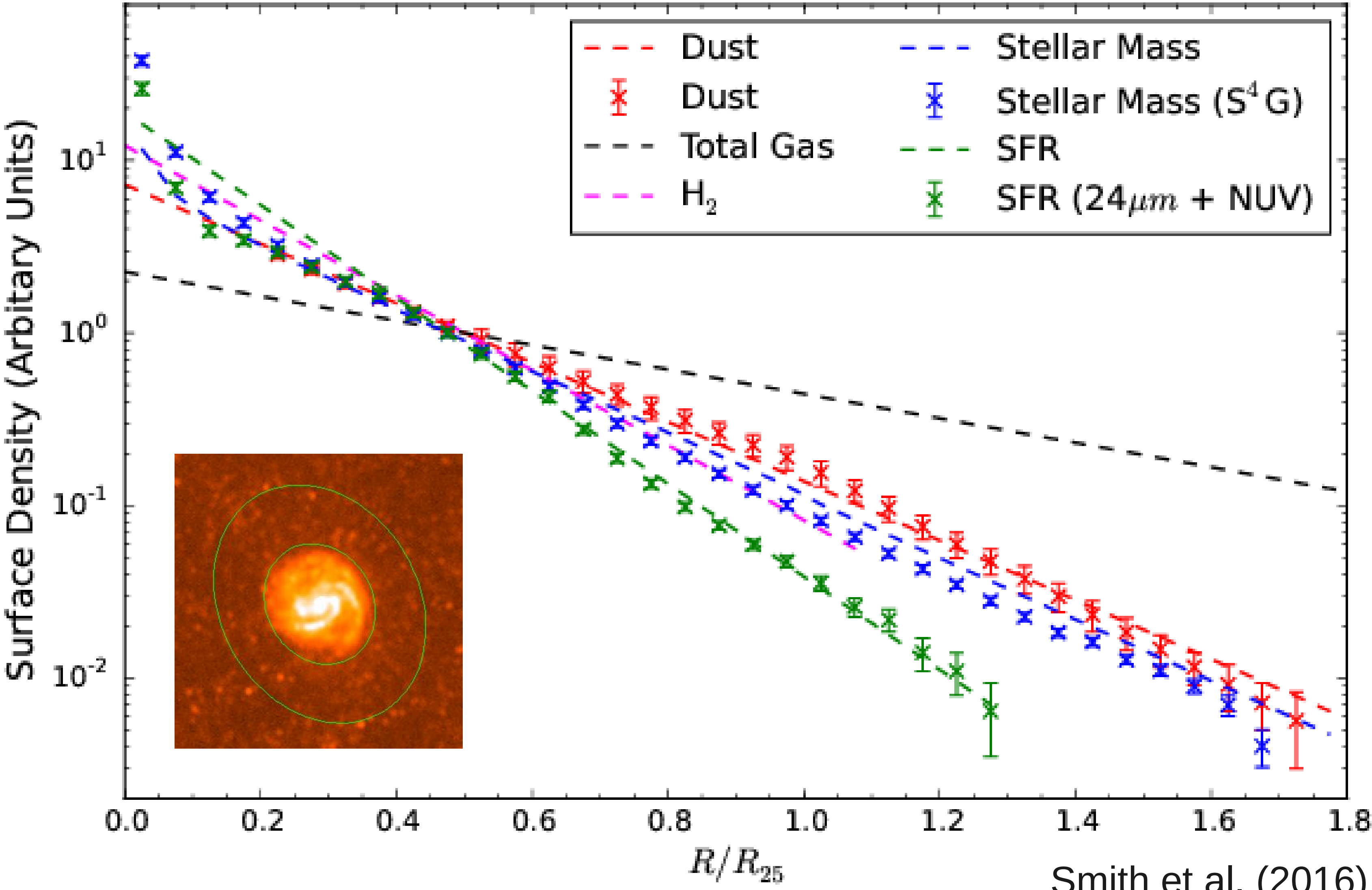
All H-ATLAS now released!

(Smith et al. 2017, Furlanetto et al. 2017, Maddox et al. 2018)

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

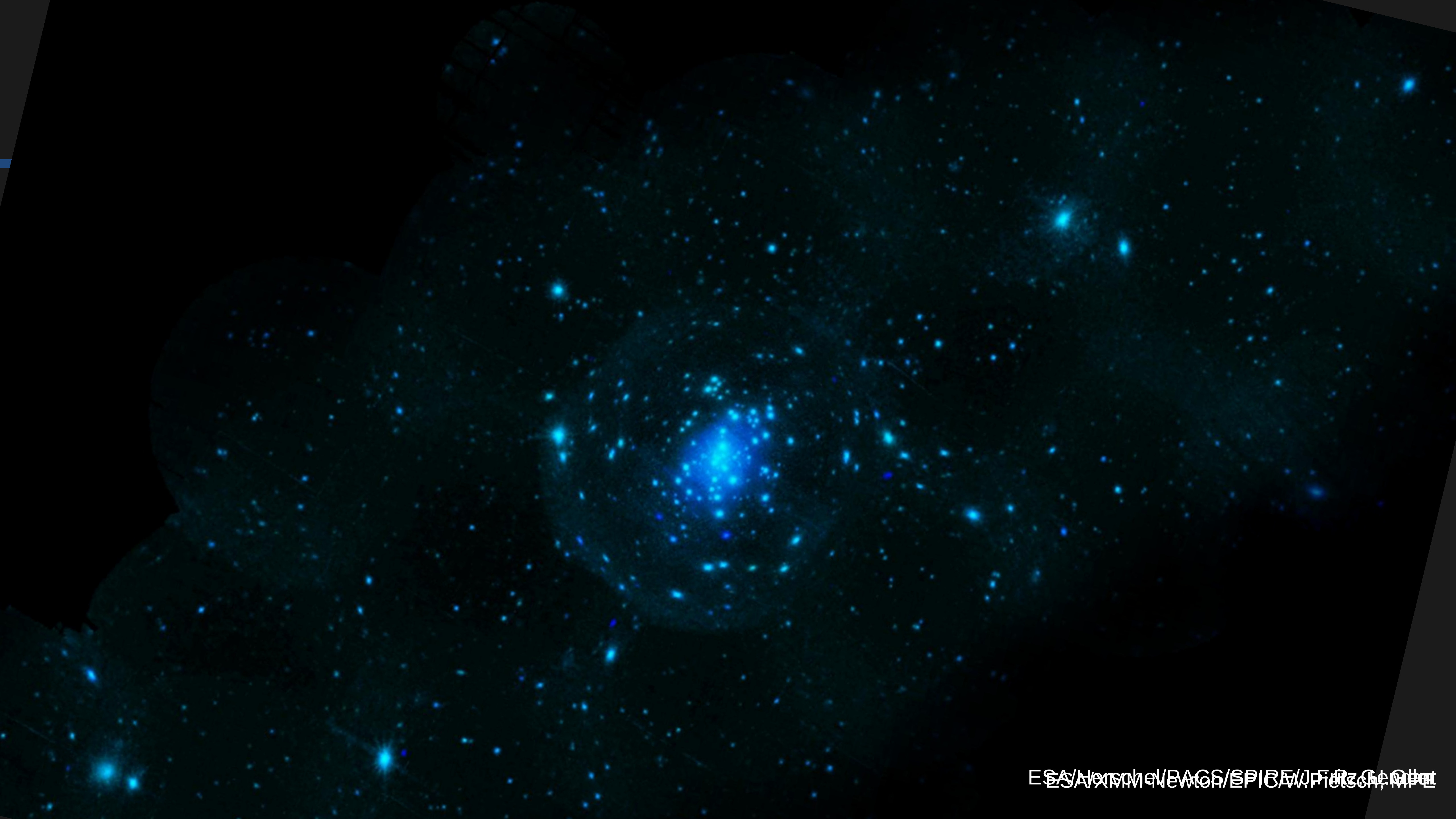
Holwerda (2009)



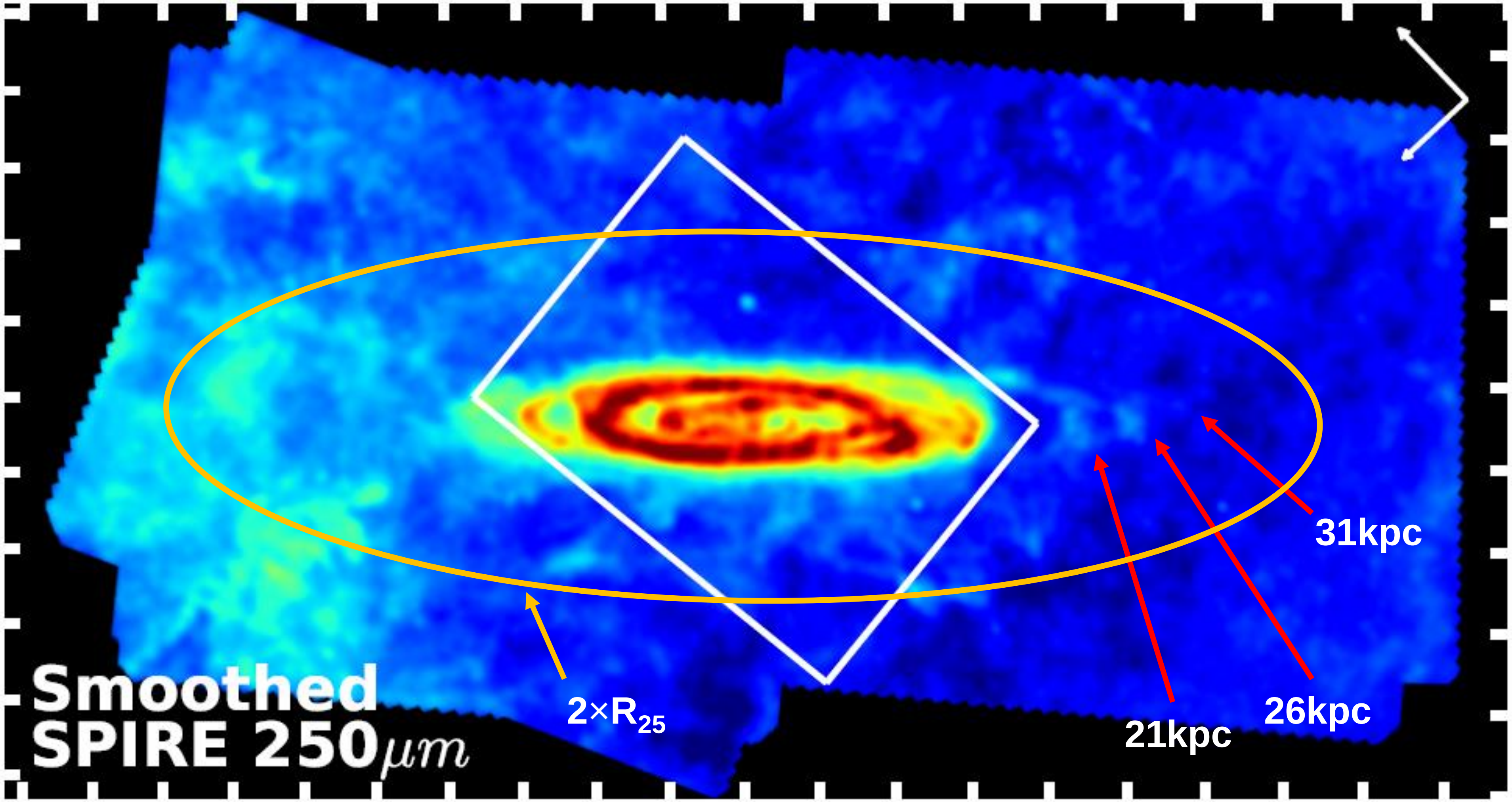
Smith et al. (2016)

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 – also see)
  - High-resolution studies of objects that cover a range of objects


ESA/Herschel/PACS/SPIRE/J. Fritz, U. Gent
ESA/XMM-Newton/EPIC/W. Pietsch, MPE

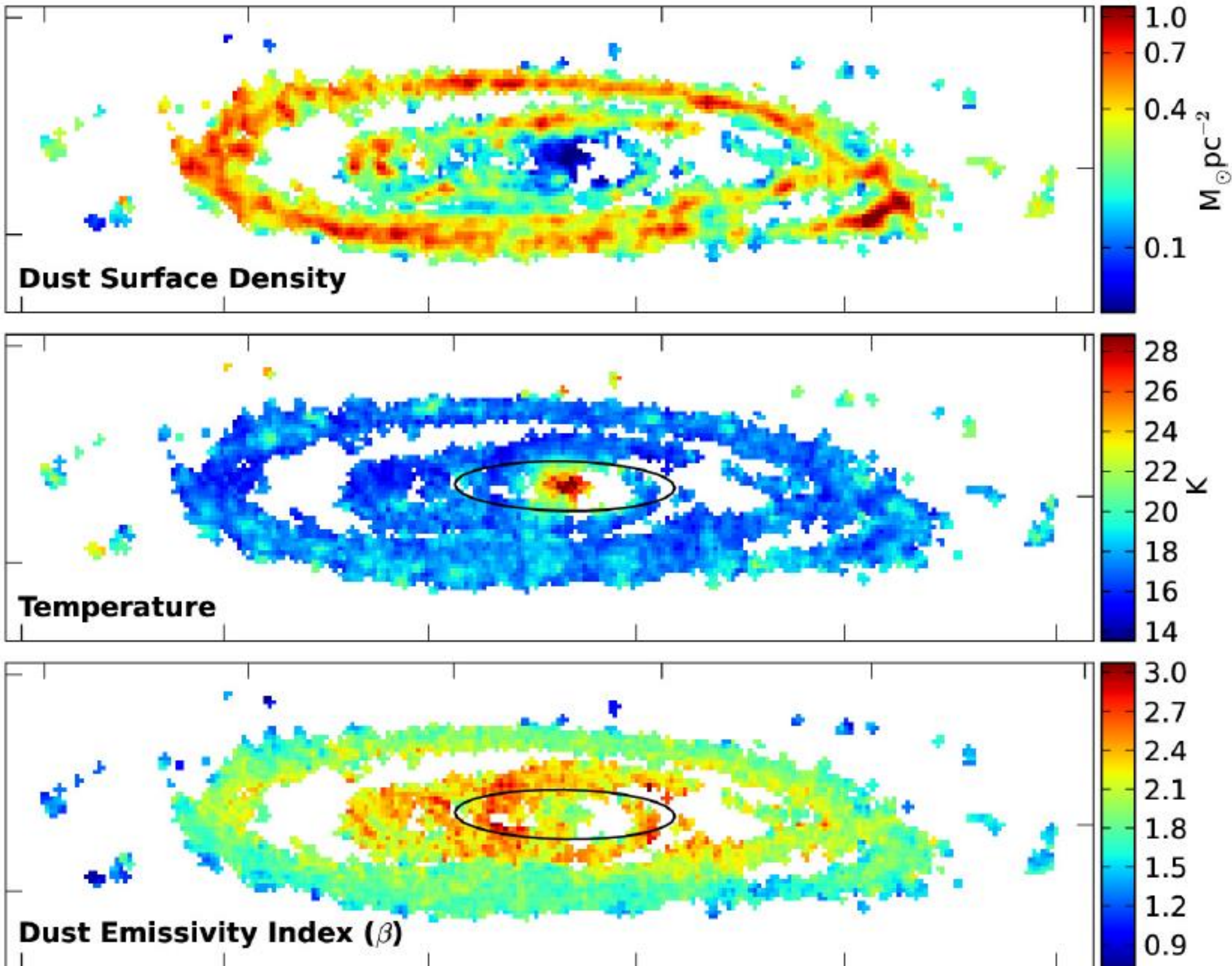
Herschel Exploitation of Local Galaxy Andromeda (HELGA)



- 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)

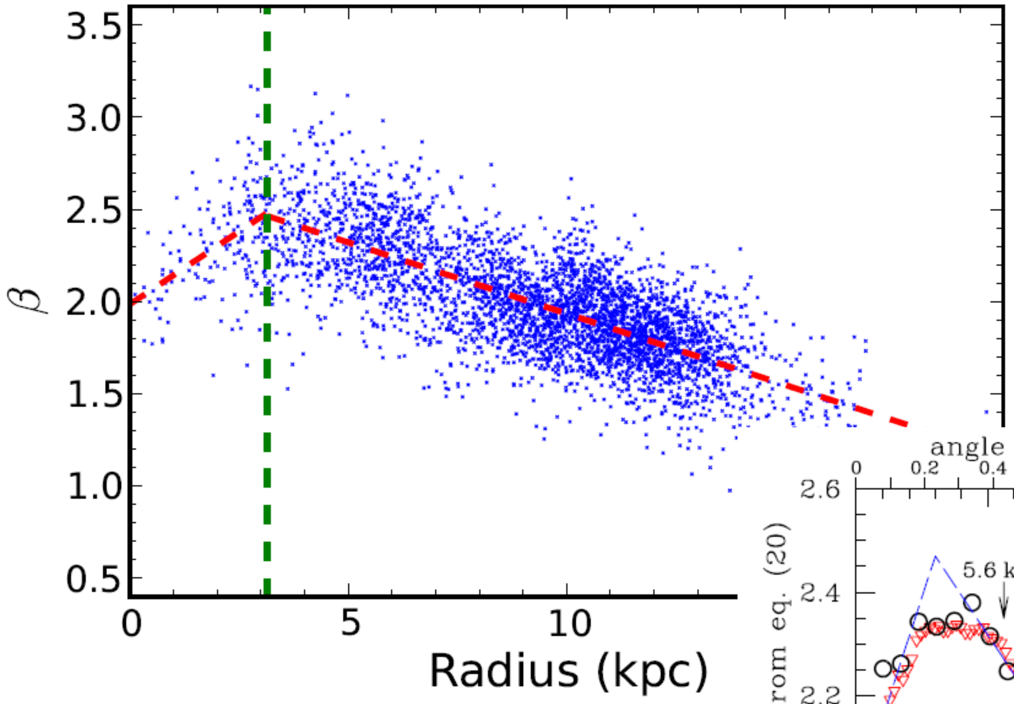
HELGA II: SED Fitting (Smith et al. 2012)

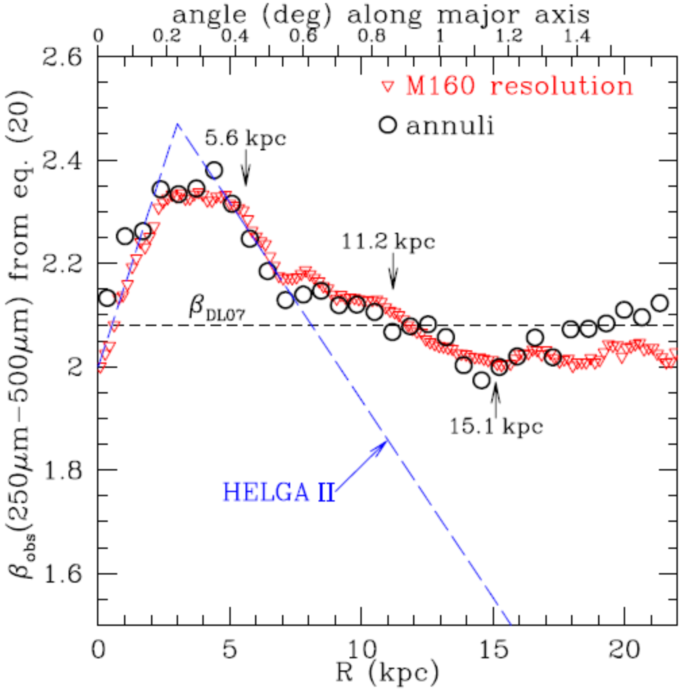
- Processing:
  - Convolve and rebin all bands
  - 140pc resolution
  - Restrict to all 5 fluxes $> 5\sigma$
  - Take into account all correlated uncertainties
  - 4000 independent pixels
- Fit 1 modified blackbody model
- Find a need for a variable β
- Method is not optimal as information is thrown 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 β 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)



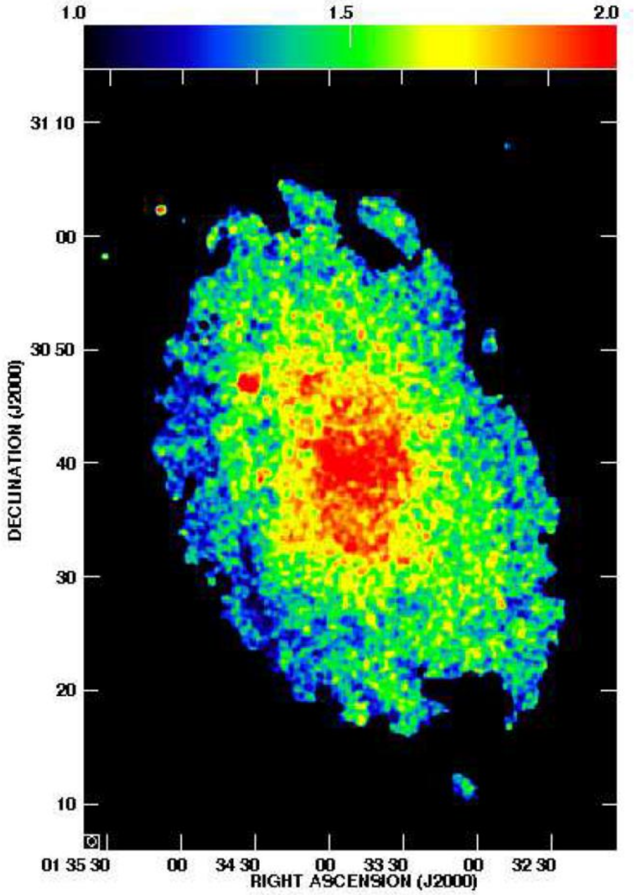


- Differences in β could be caused by changes in the grain size, icy mantles, or freshly formed grains.
- Problem is no obvious correlation with say properties of molecular gas to provide shielding etc…

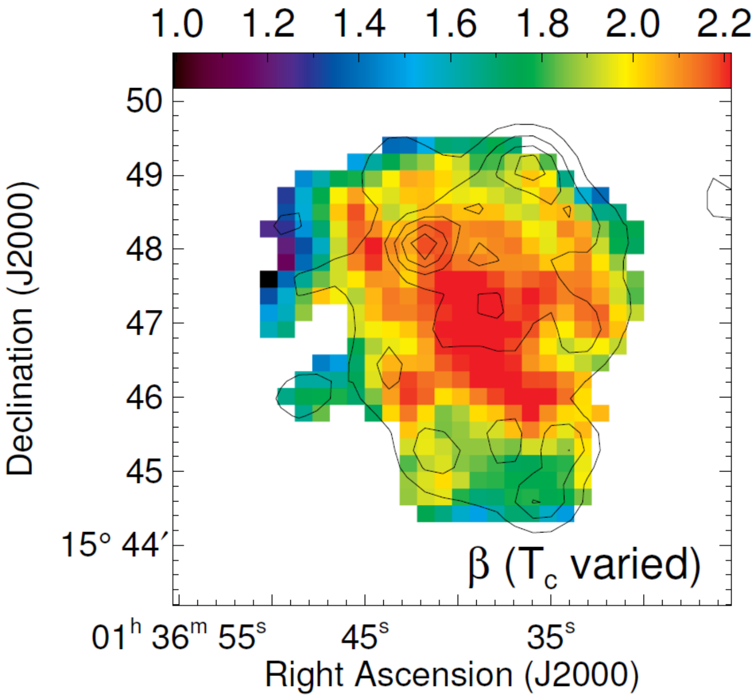
Variations of β in Other Galaxies

- Many studies have seen variations in other objects

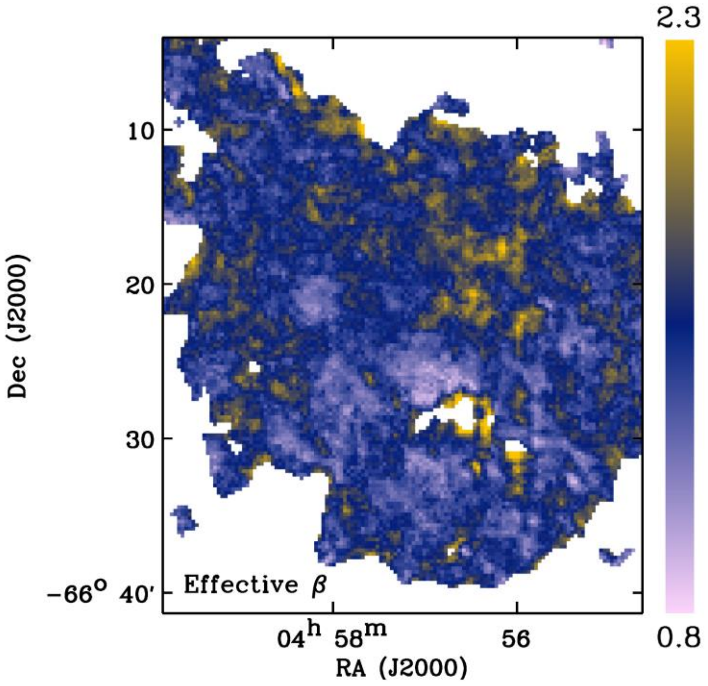
M33
Tabatabaei et al. 2013



KINGFISH 20 galaxies
(NGC0628)
Kirkpatrick et al. 2014

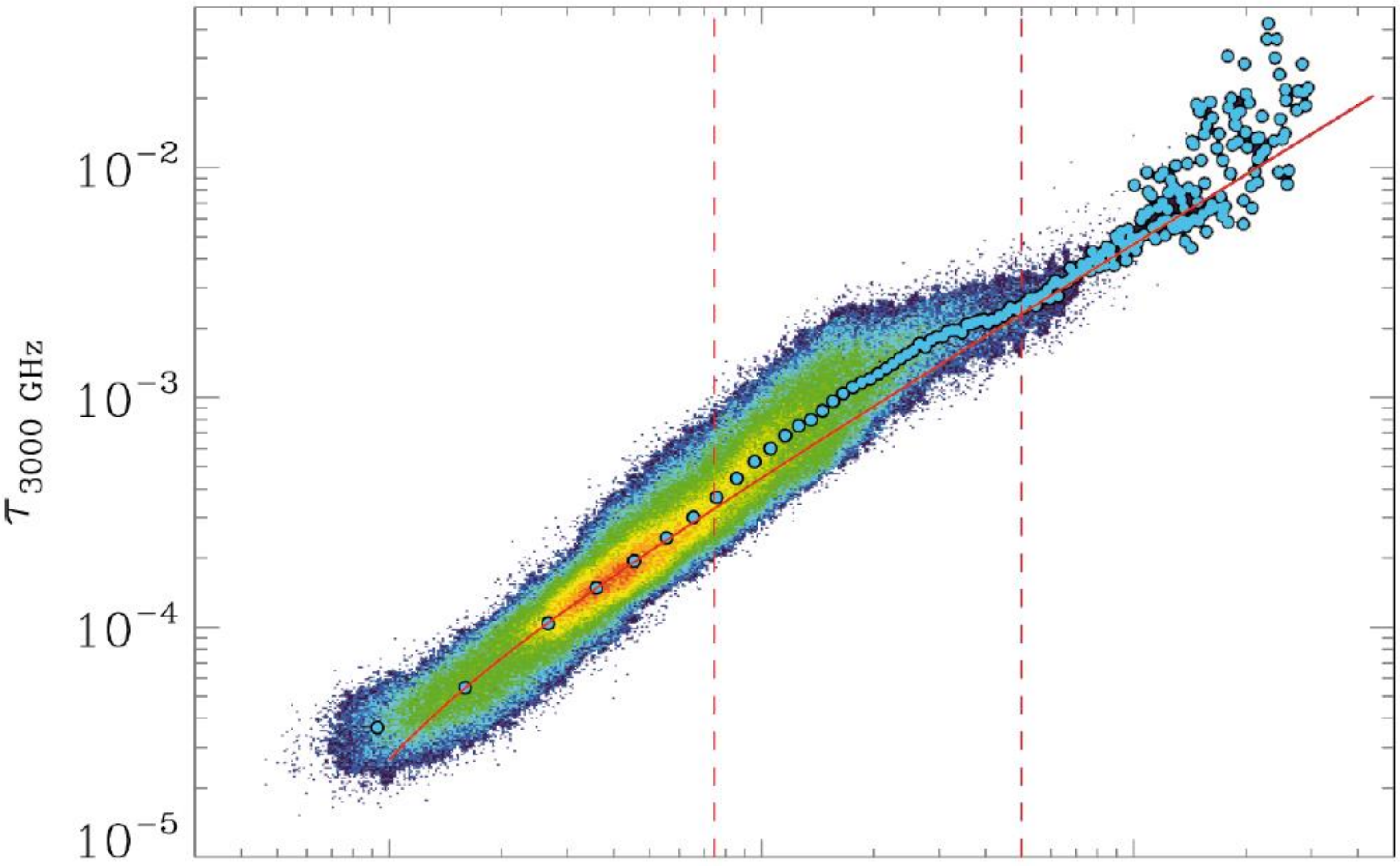


LMC Complex N11
Galametz et al. 2015



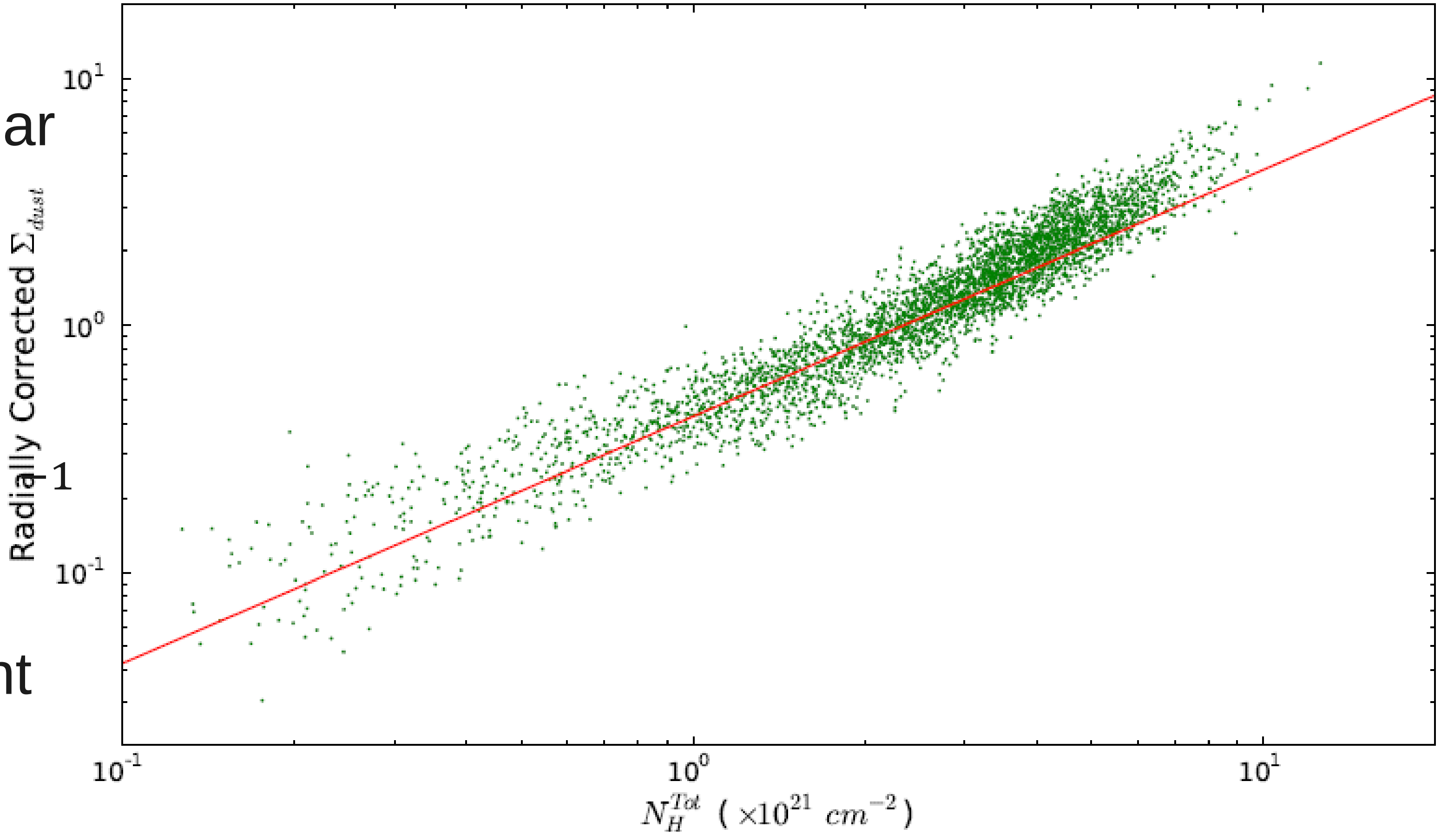
Planck – Dark Gas (2011)

- $\tau = \left(\frac{\tau_d}{N_H}\right)^{ref} \cdot N_H^{obs} + con$
- Dark gas → 28% of atomic gas, 118% of H_2
- Average X-factor 2.54

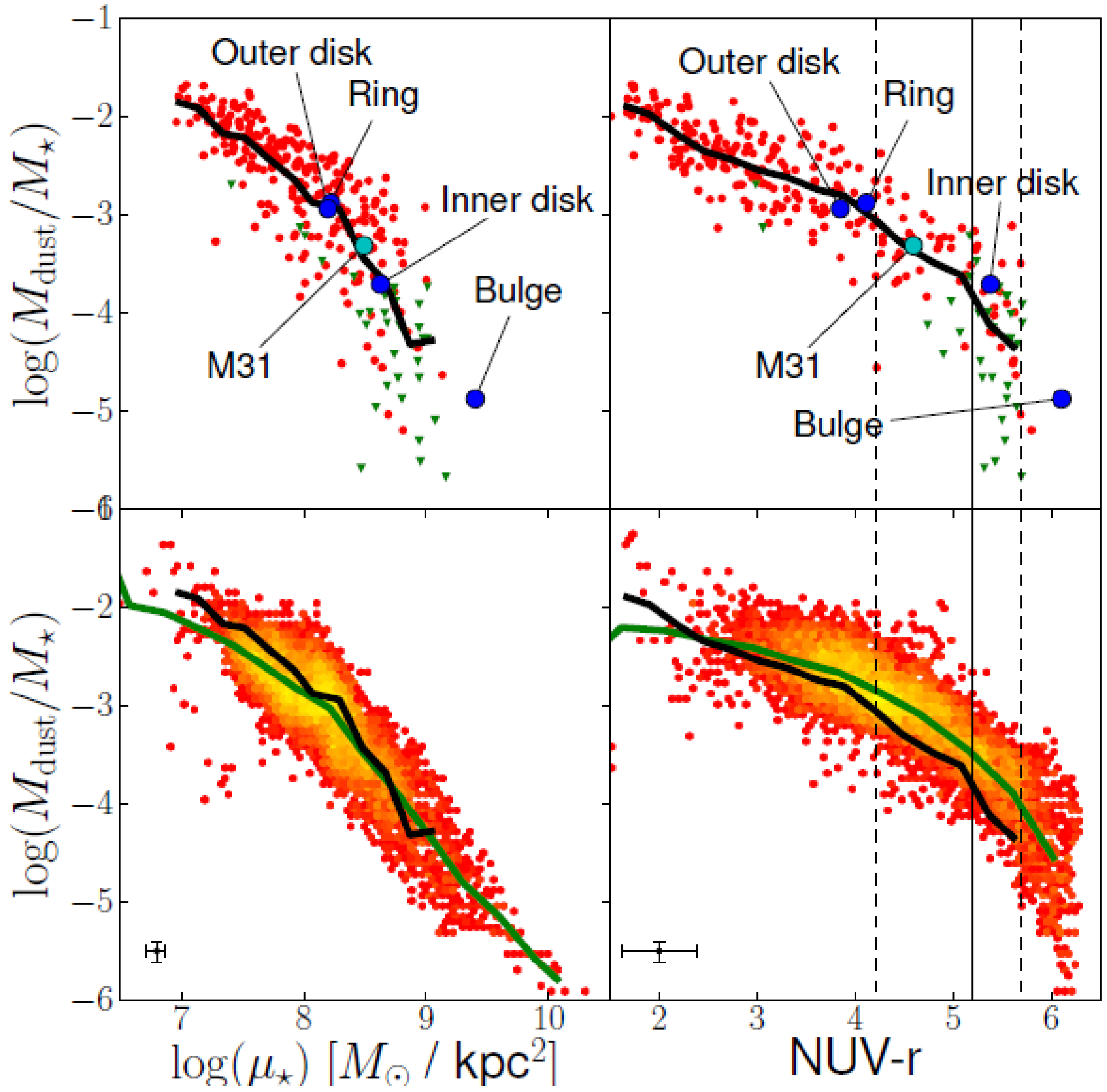


Is there Dark Gas in Andromeda?

- Adjusted for radial metallicity gradient
- No region dominated by molecular gas
- Line-if-sight averaging
- Best fit X-factor $(2.0 \pm 0.4) \times 10^{20}\ \mathrm{cm}^{-2}\ [\mathrm{K\ km/s}]^{-1}$
- 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)

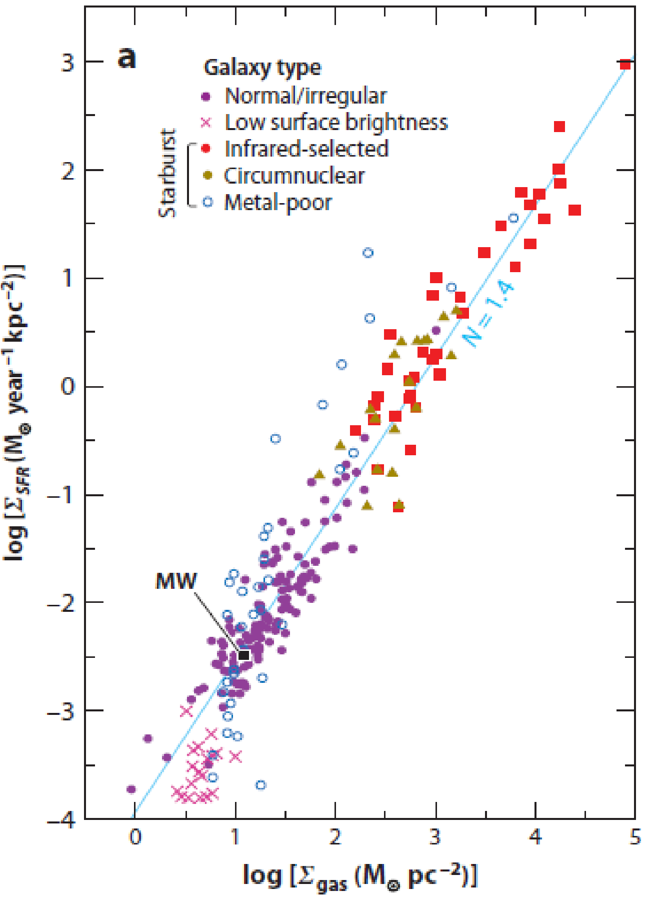


- MAGPHYS panchromatic fits to entire image
- Individual regions fit on global dust scaling relations (Cortese et al.)

Star-Formation Law in Galaxies

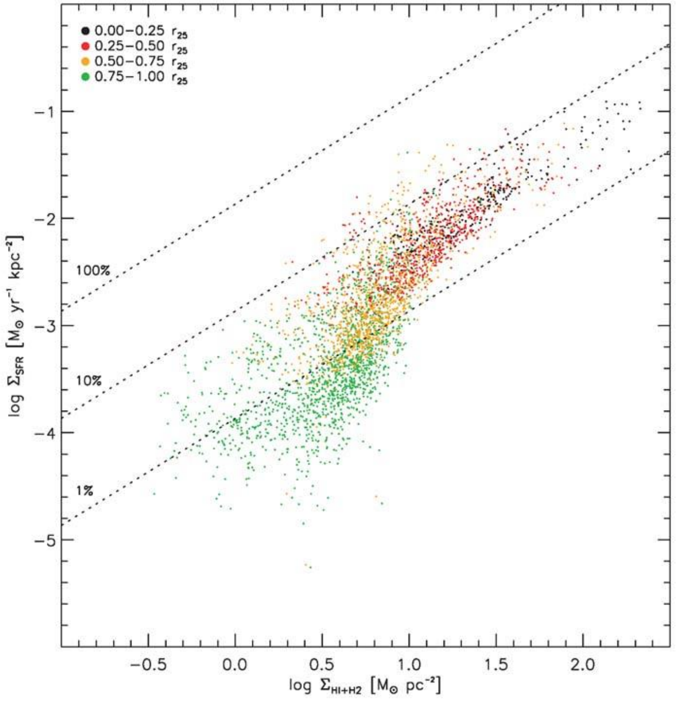
- Ultimate goal, to understand the key physical drivers and regulators of star-formation, and their defining physical relationships
- Andromeda (& soon M33) are unique as can get detailed SFH and current SFR as resolve individual stars with Hubble
- Breaks down in ULIRGS, and low metallicities
- For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

Global Scale



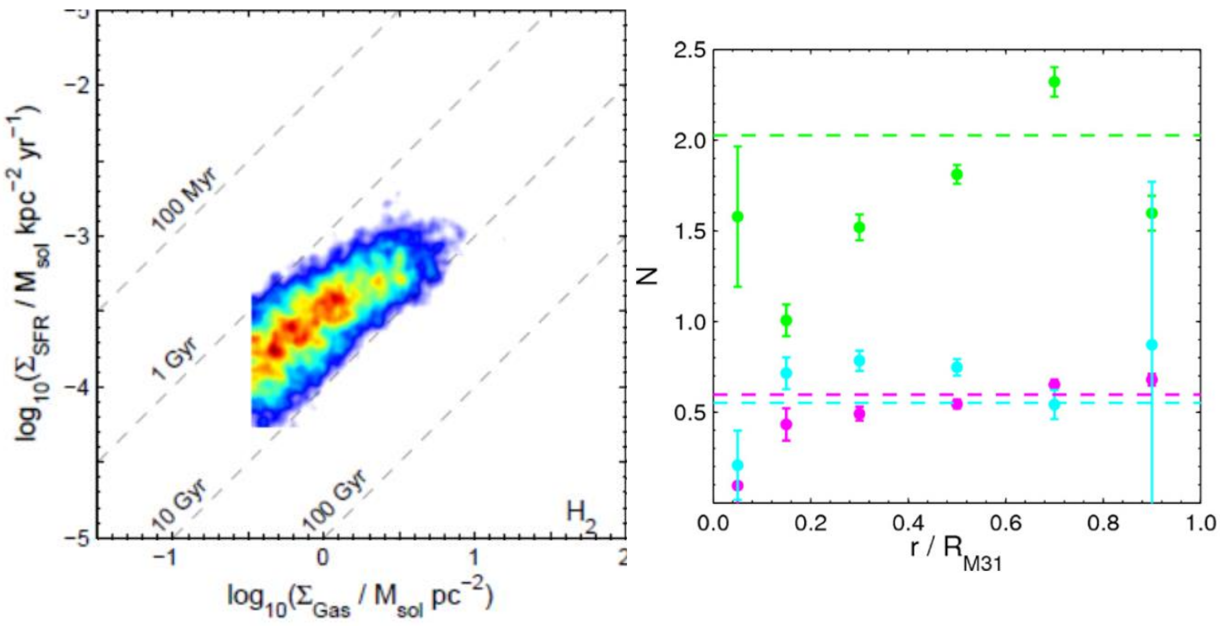
Kennicutt (multiple refs)

Nearby Galaxies



Bigiel et al. 2008 (THINGS)

Andromeda – HELGA III



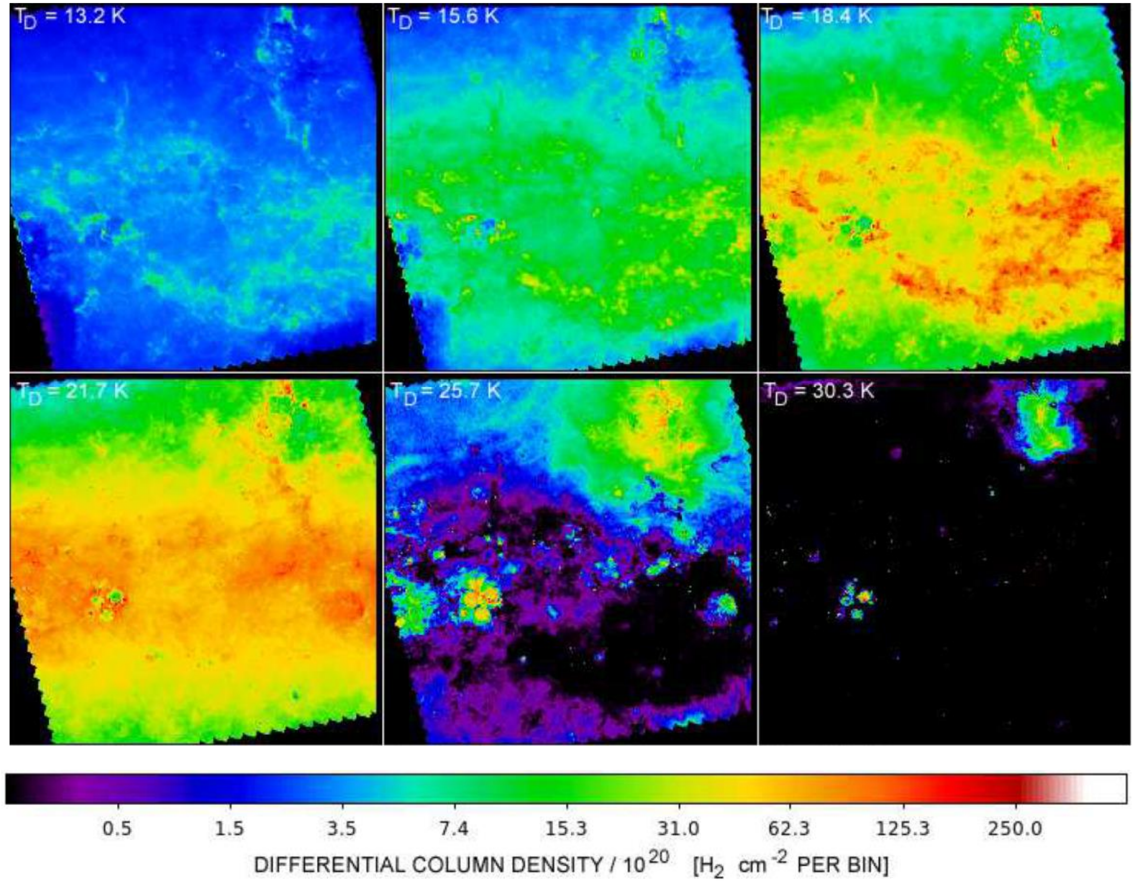
Ford et al. 2013

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 – Marsh et al. (2015)

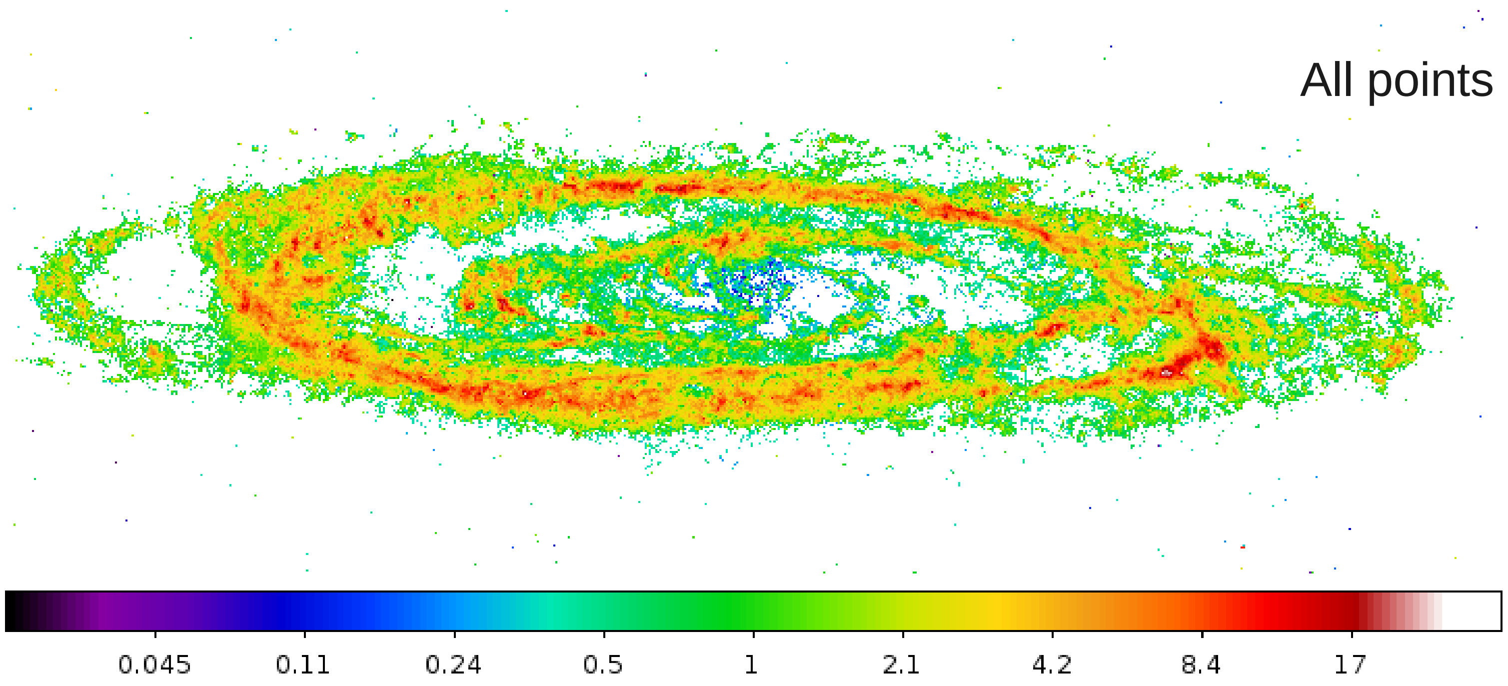


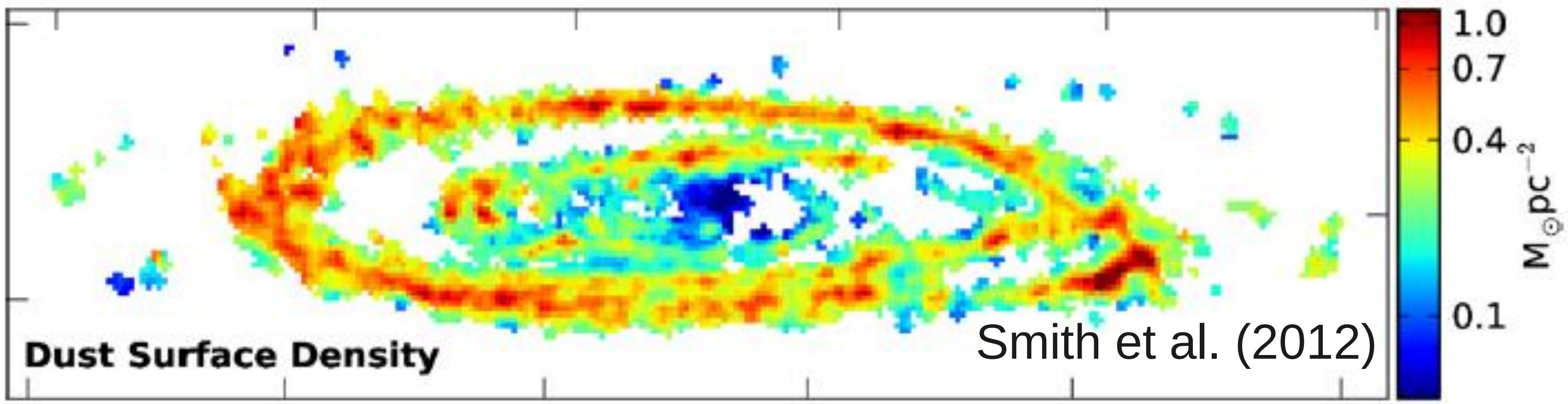
(slightly abbreviated image)

- 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 K
- T = 11.6 K
- T = 13.4 K
- T = 15.5 K
- T = 18.0 K
- T = 20.8 K
- T = 24.1 K
- T = 27.8 K
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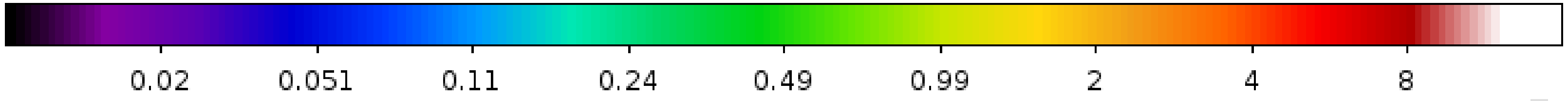
- T = 43.2 K
- T = 50.0 K



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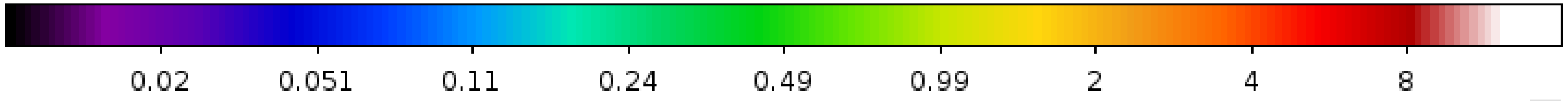

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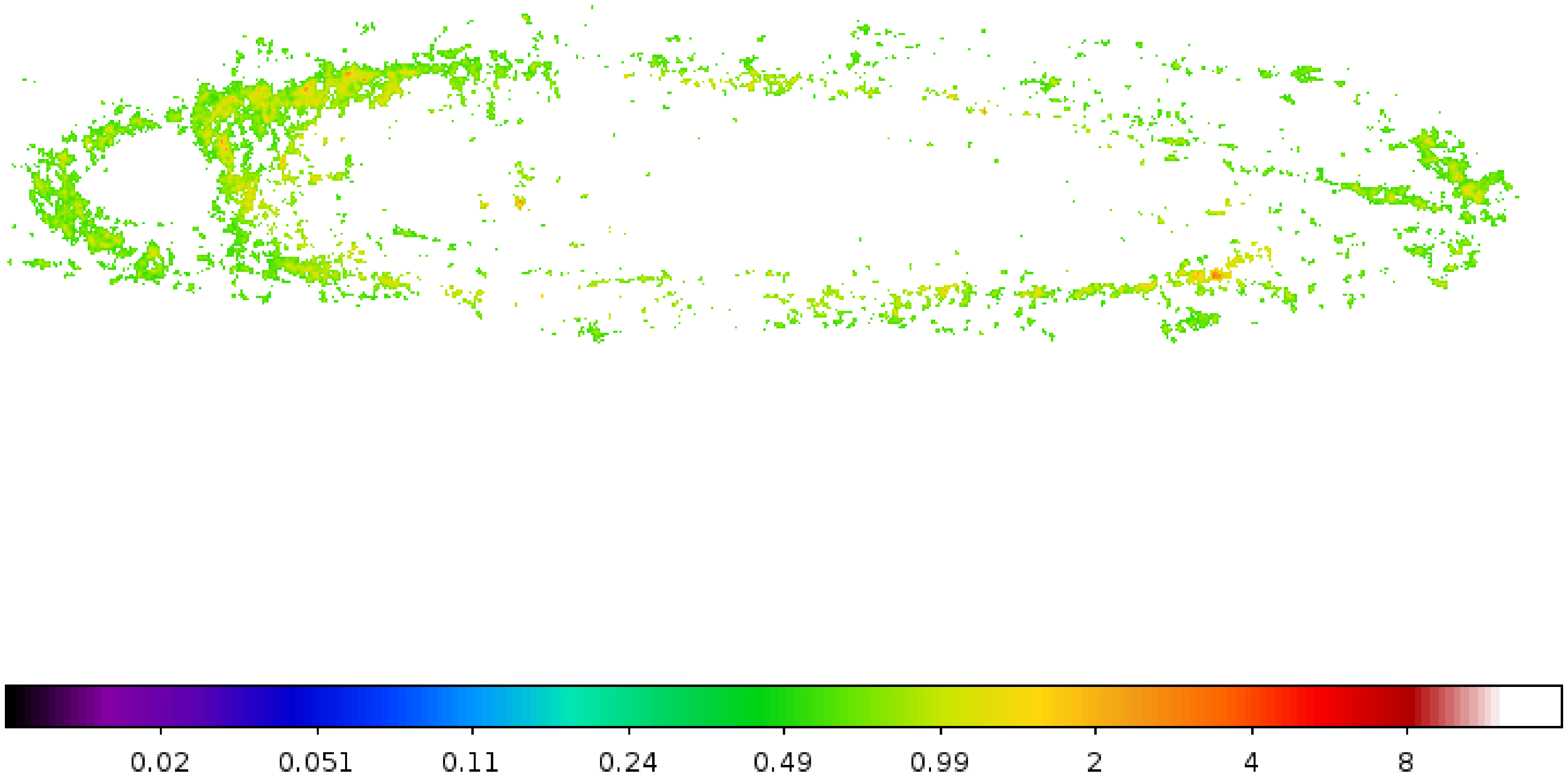

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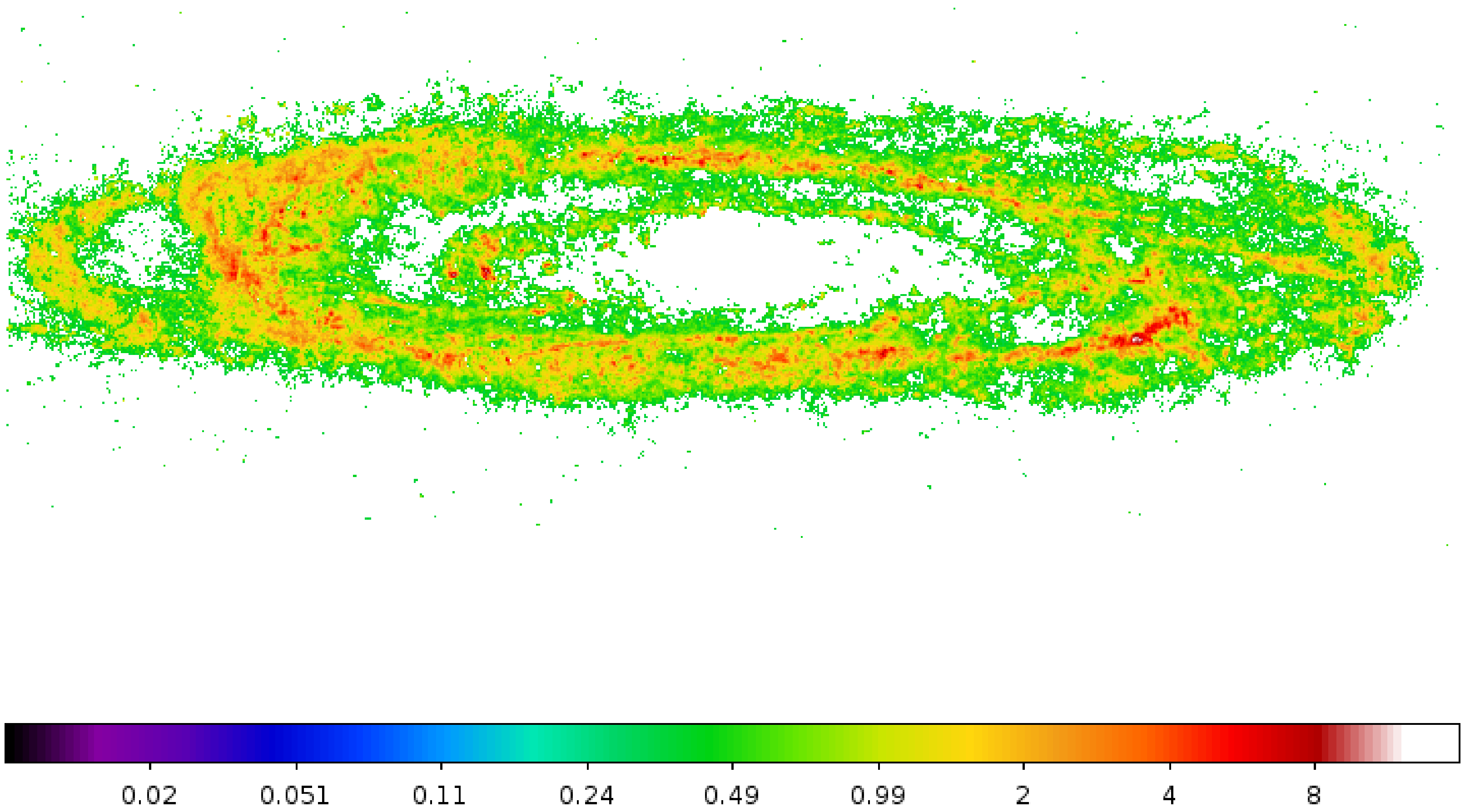

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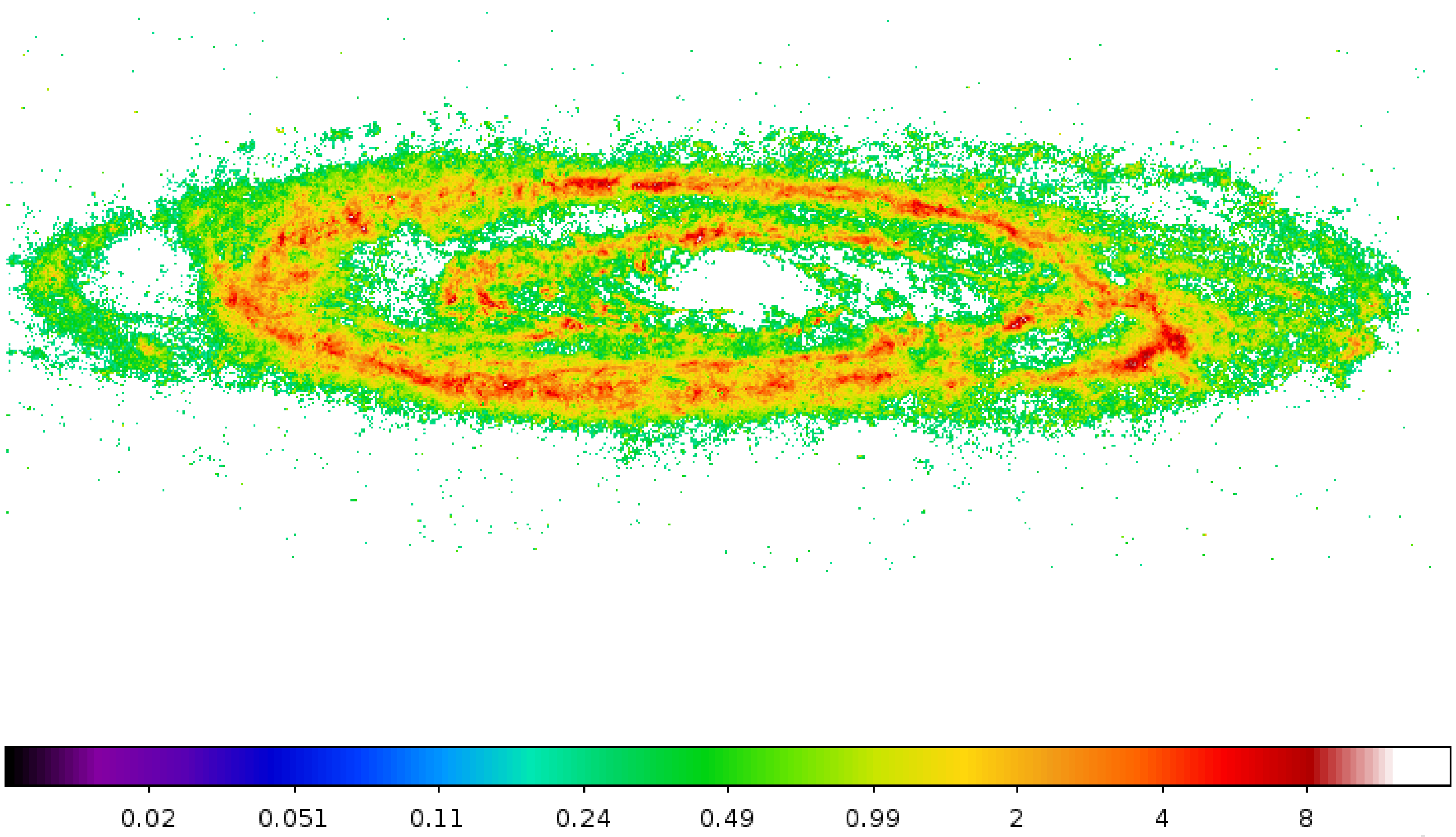

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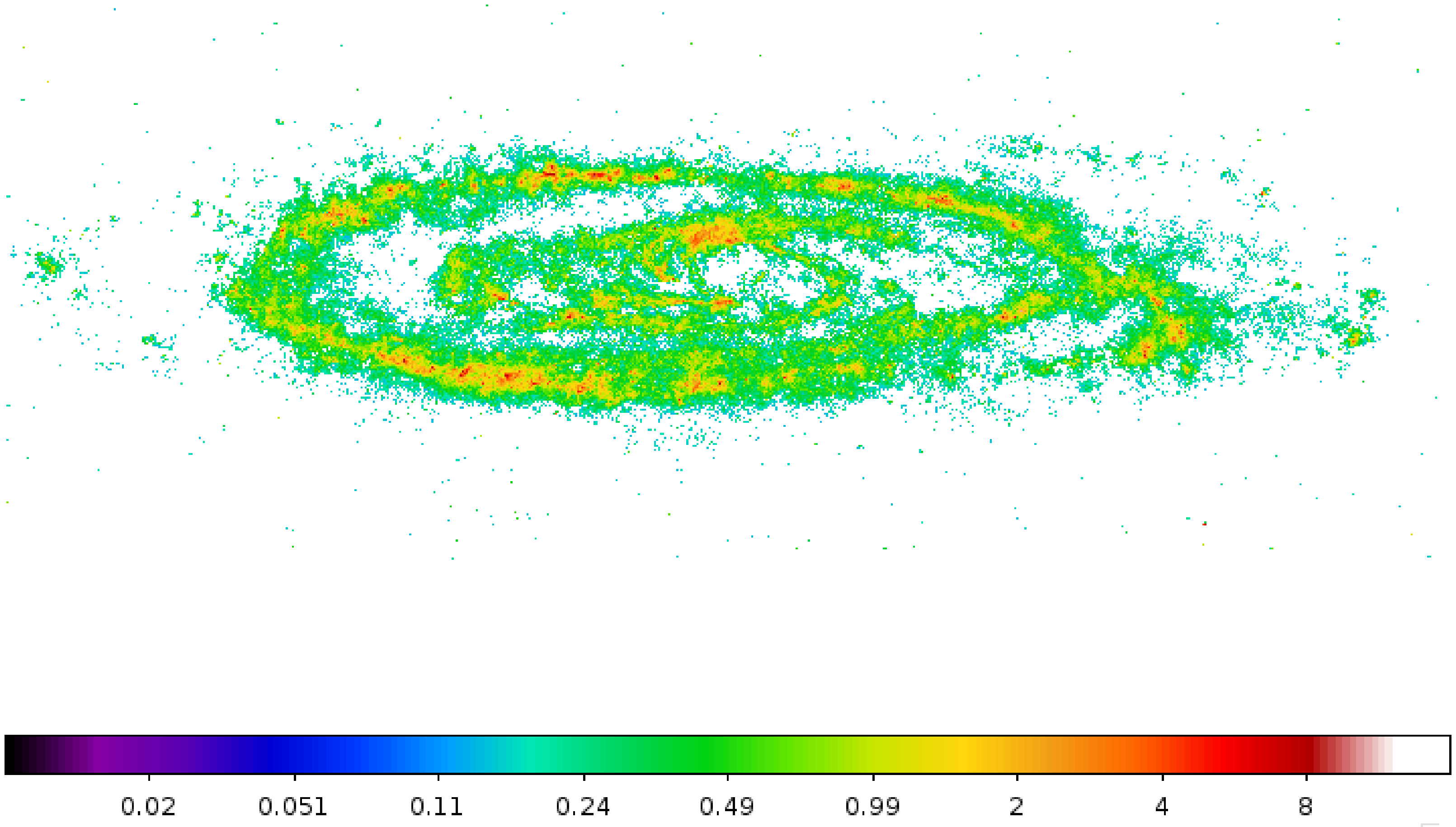

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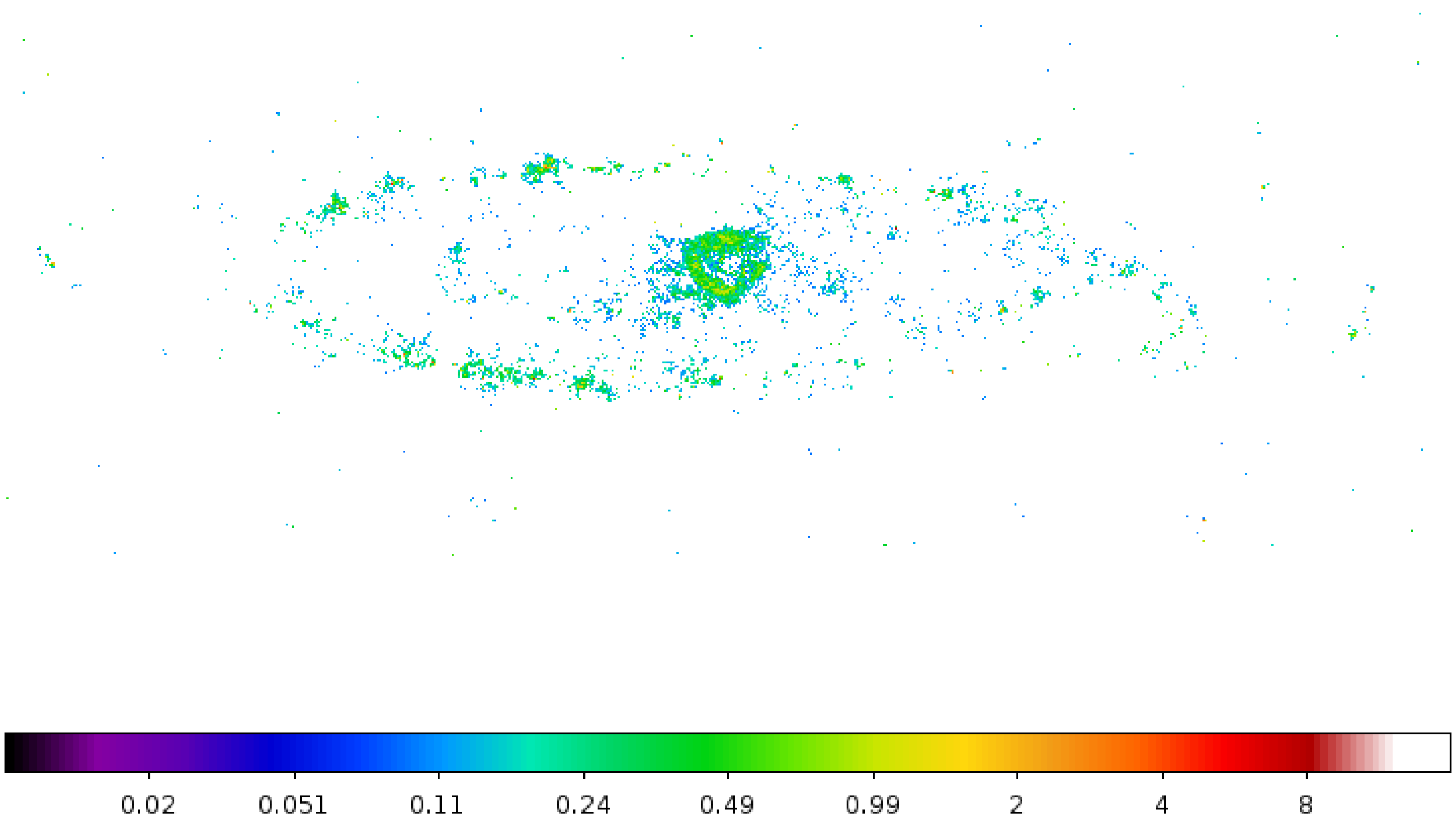

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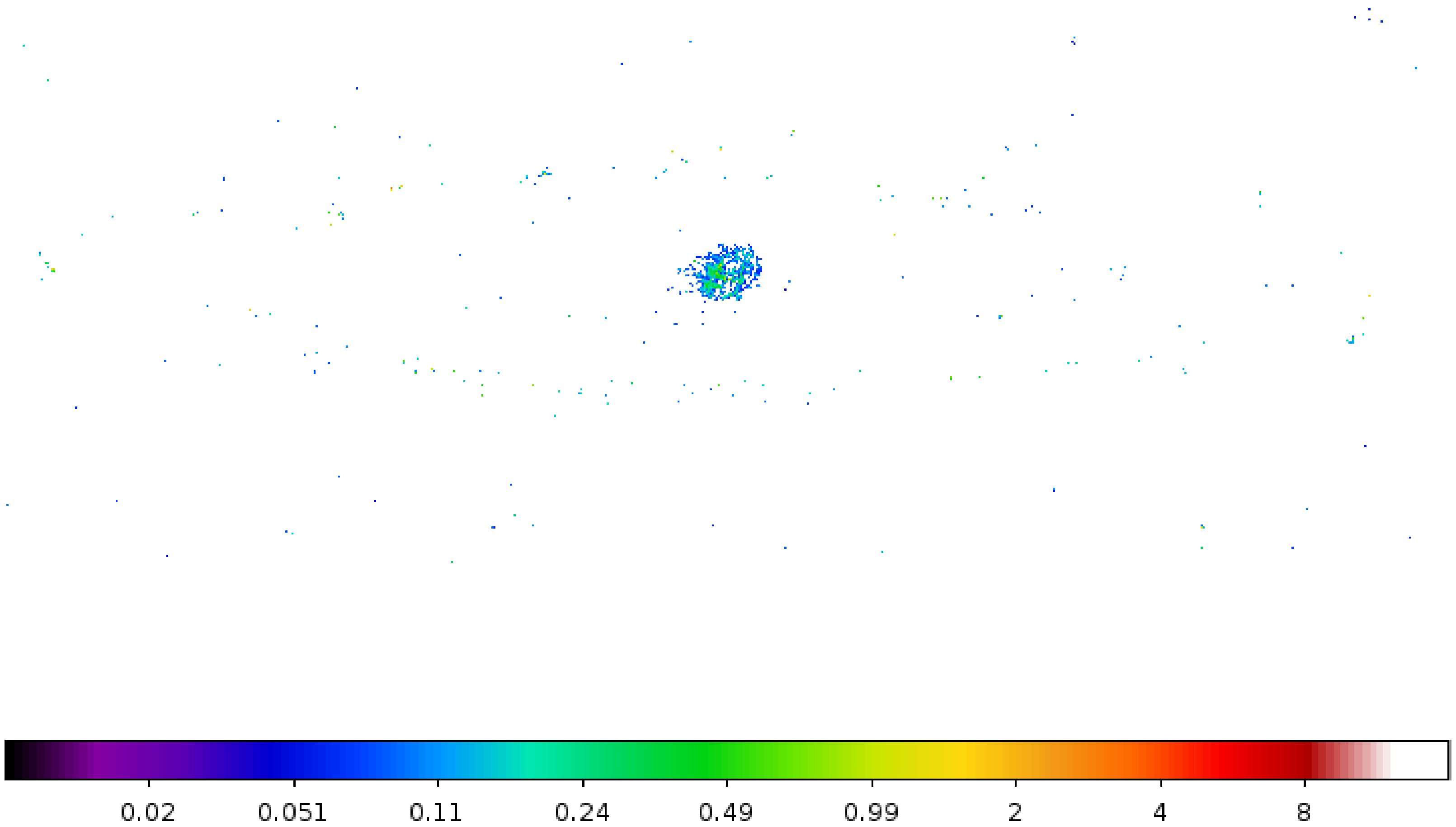

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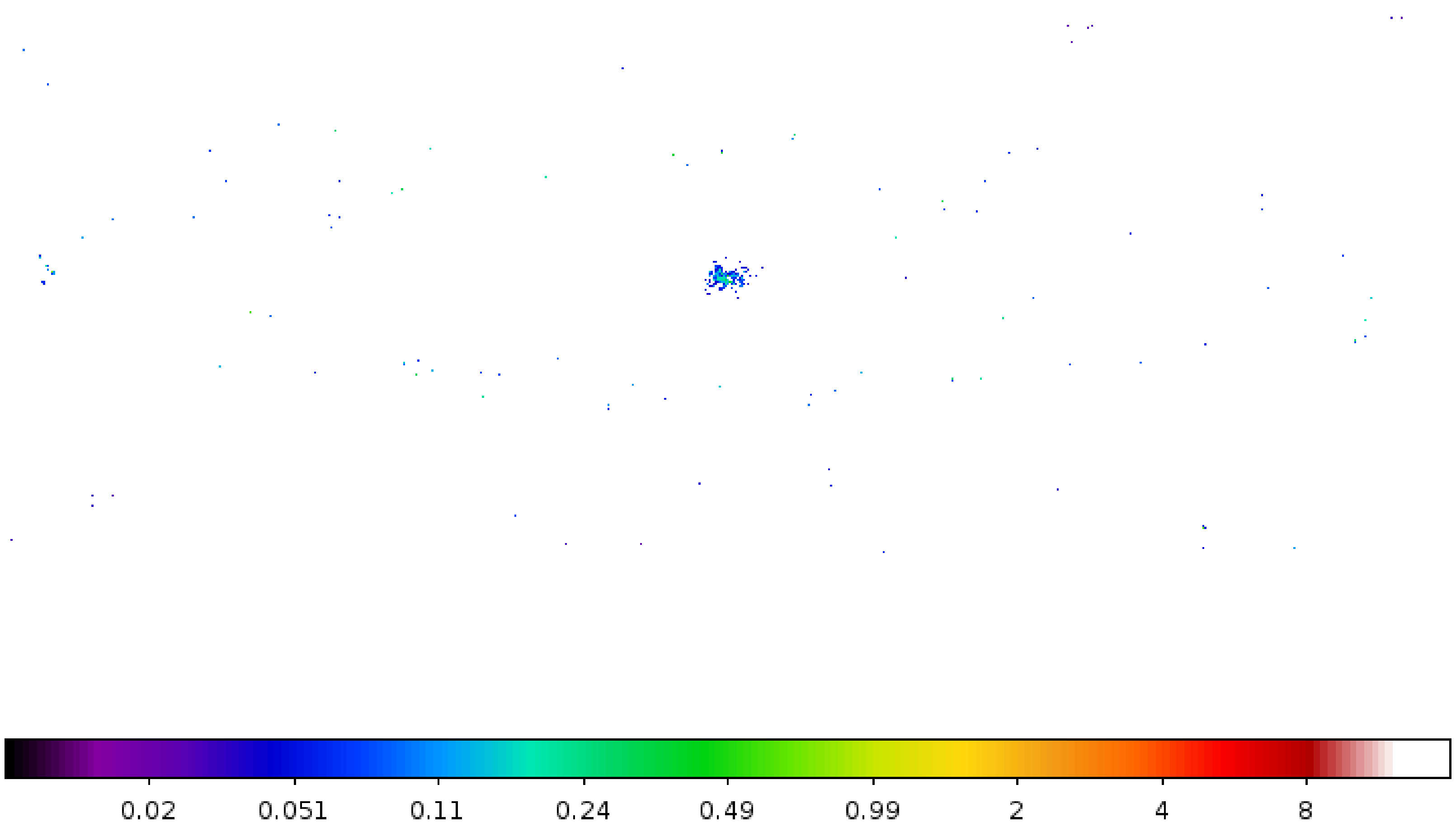

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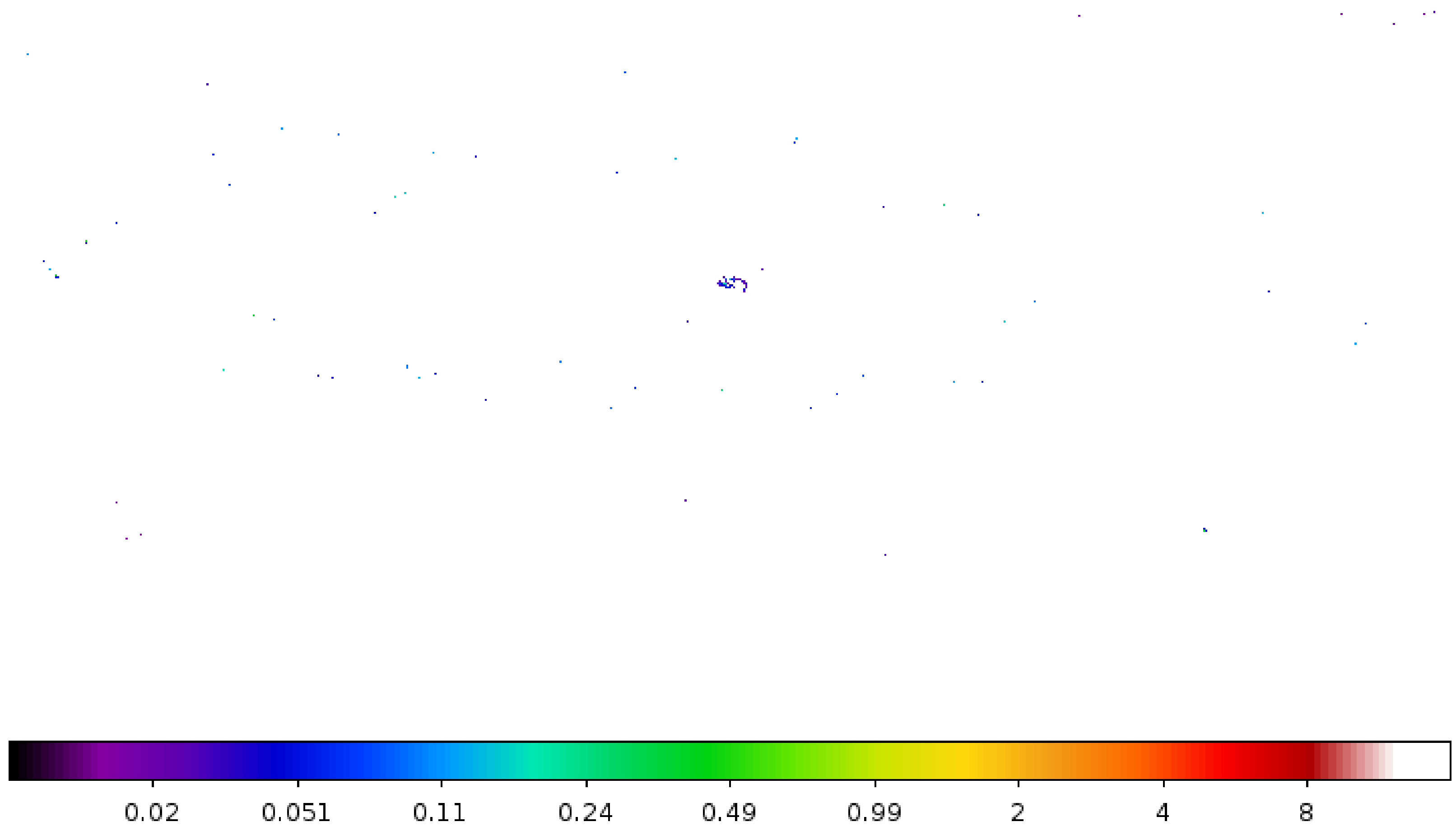

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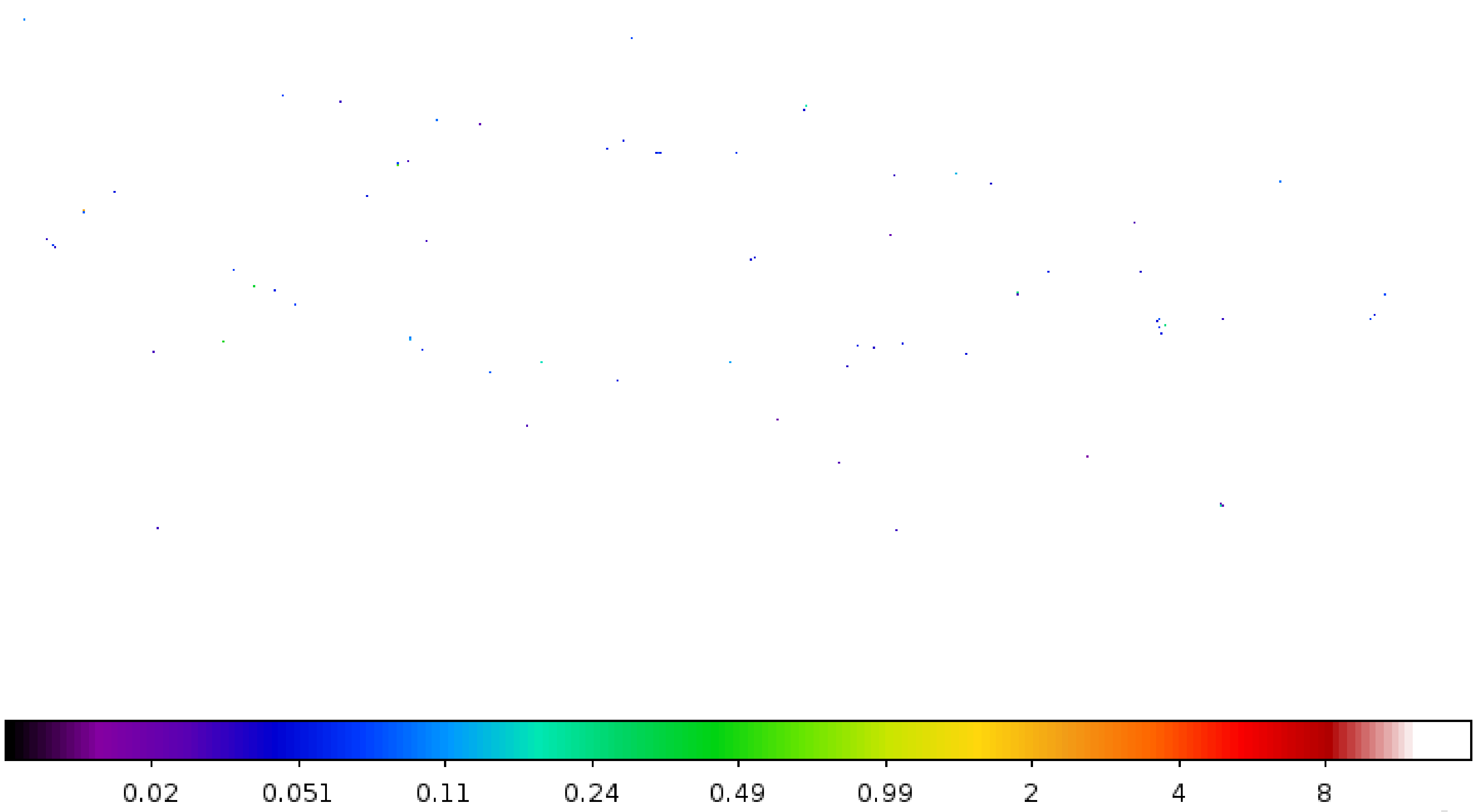

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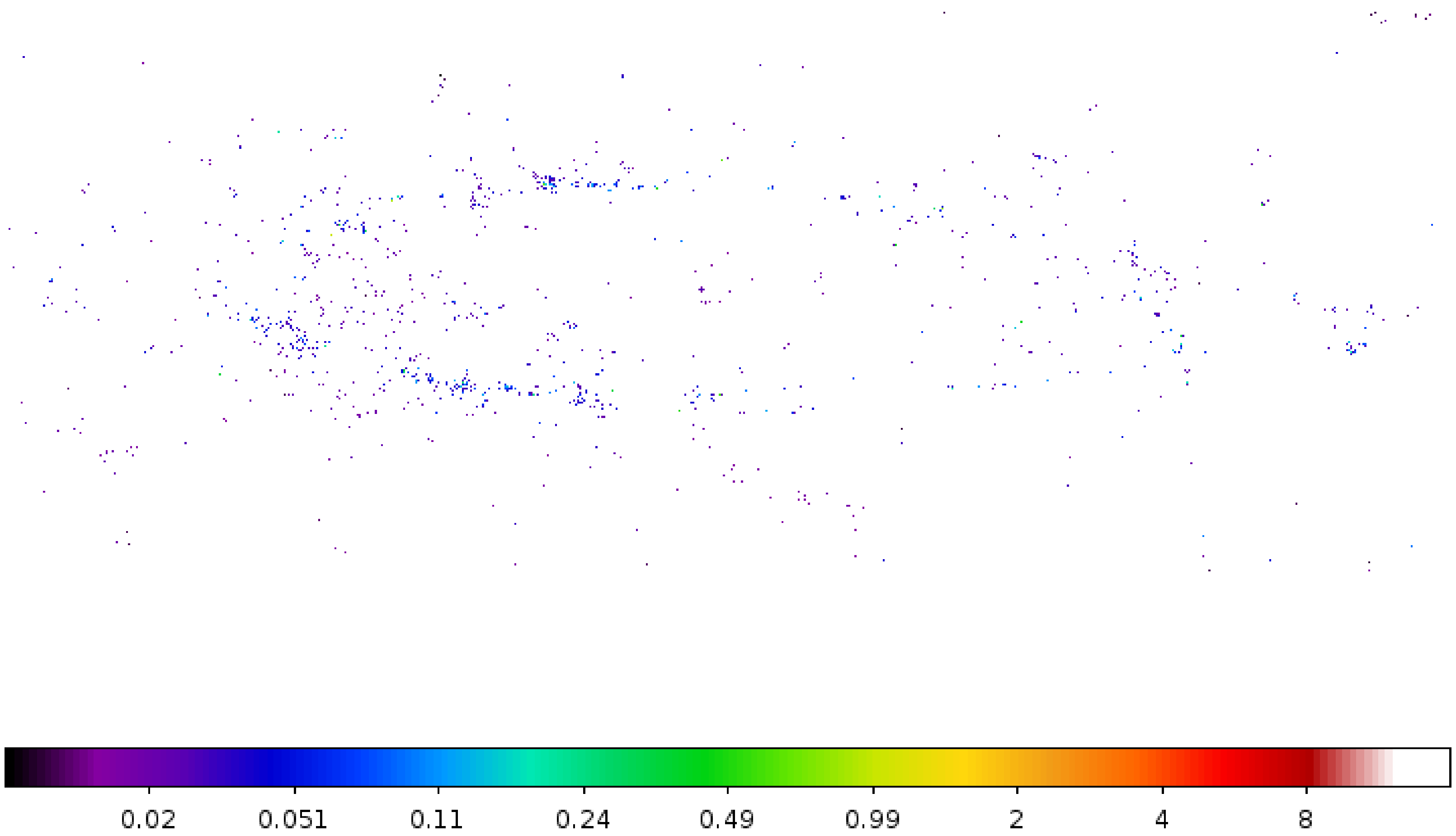
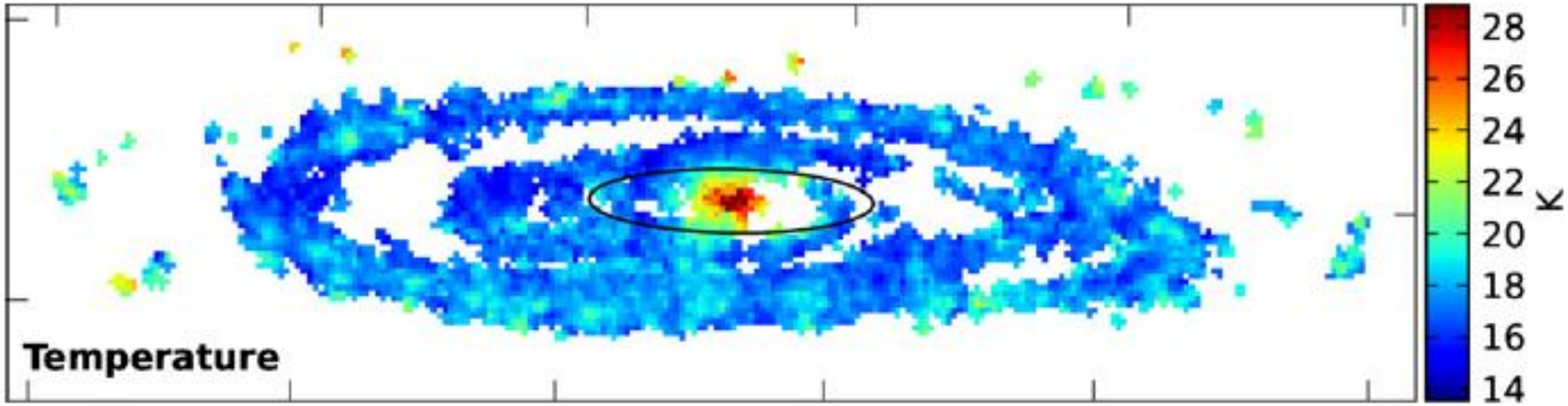
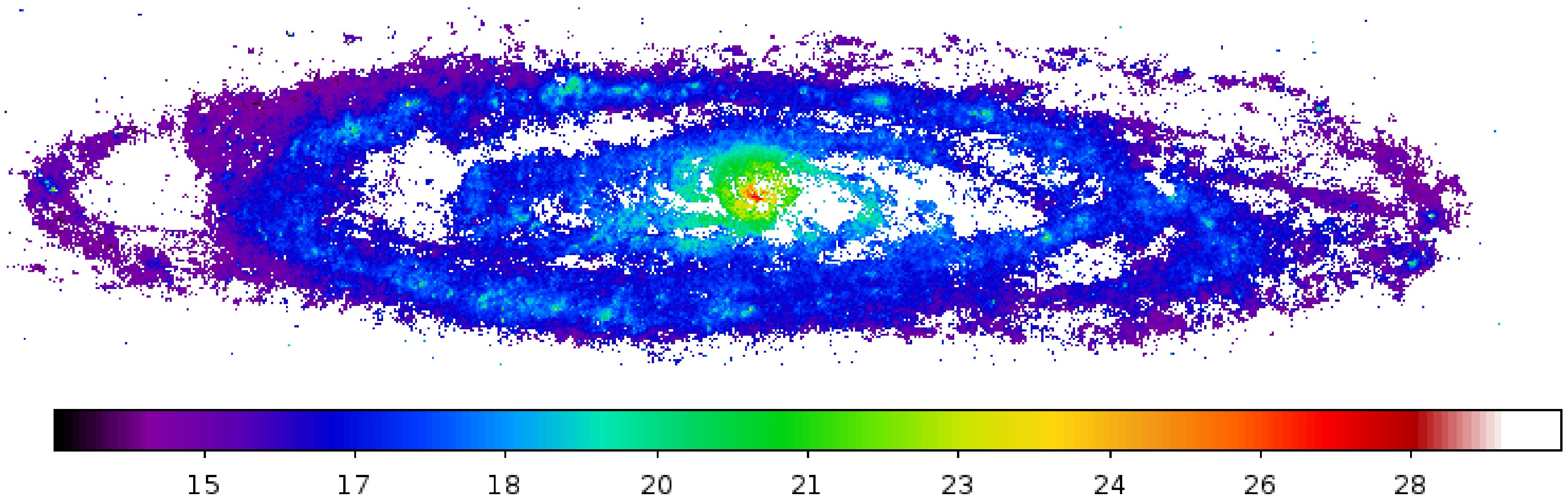


PPMAP temperature

Smith et al. (2012)

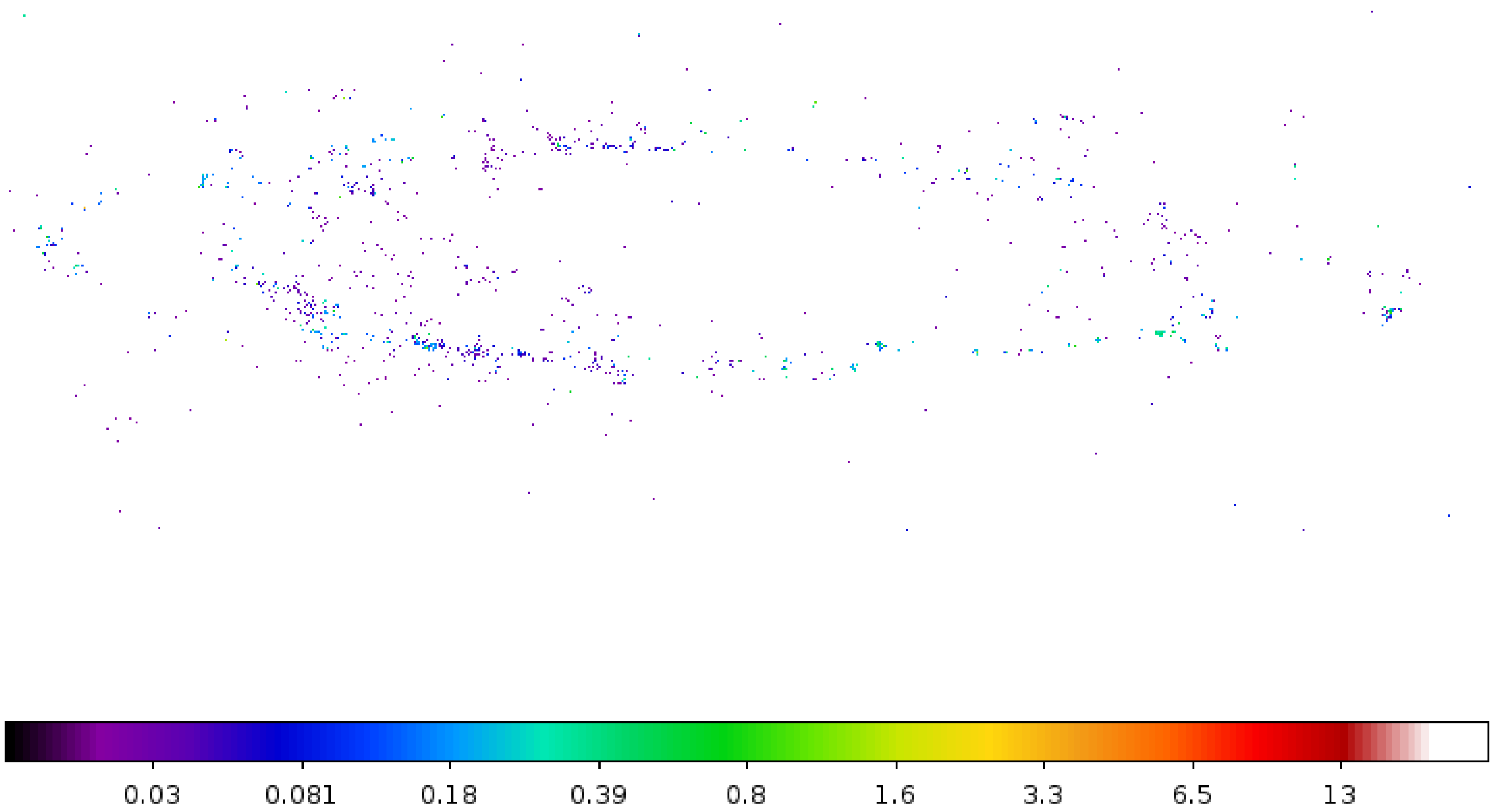


PPMAP



What about β?

- β = 1.0
- β = 1.5
- β = 2.0
- β = 2.5



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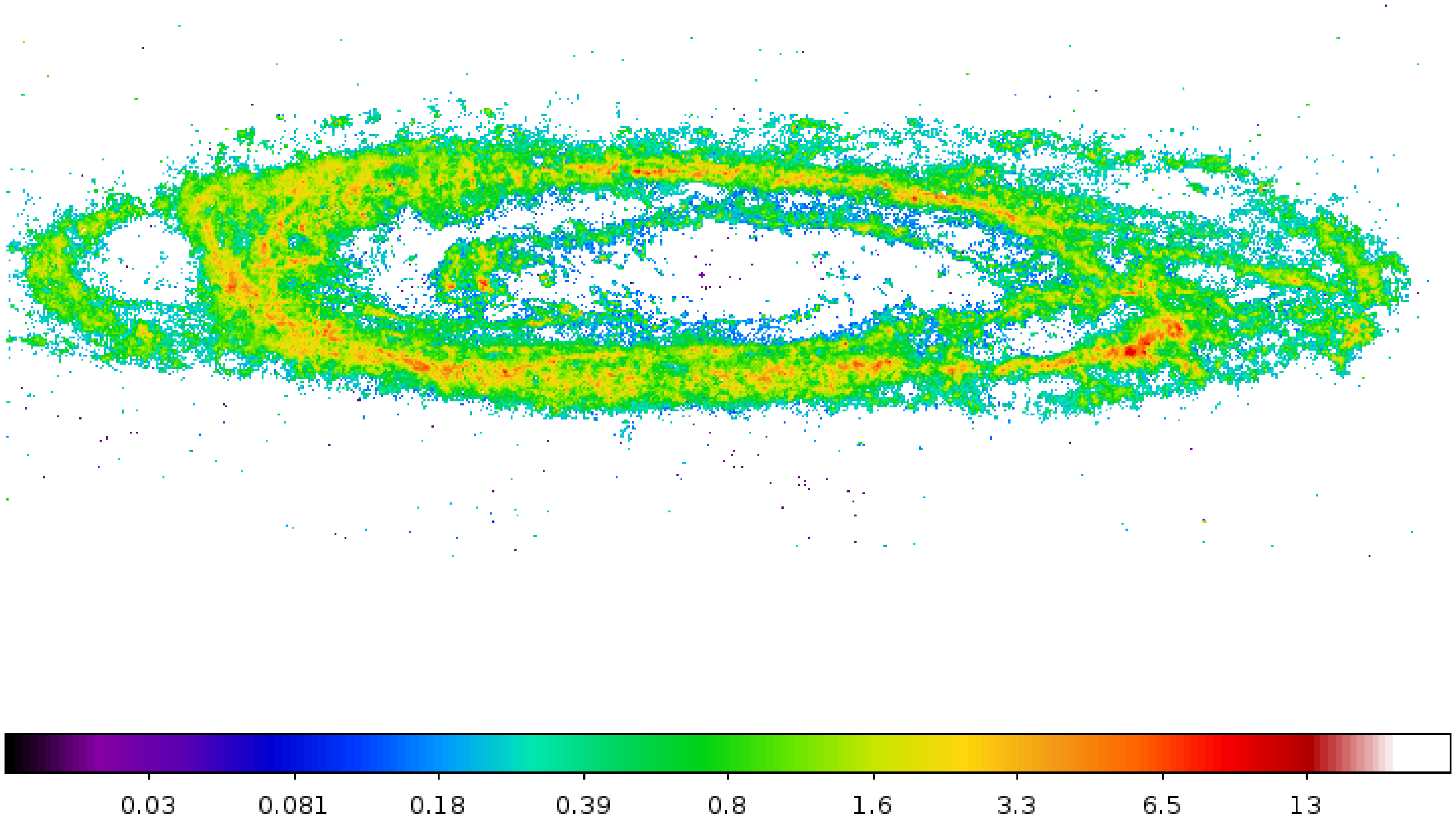

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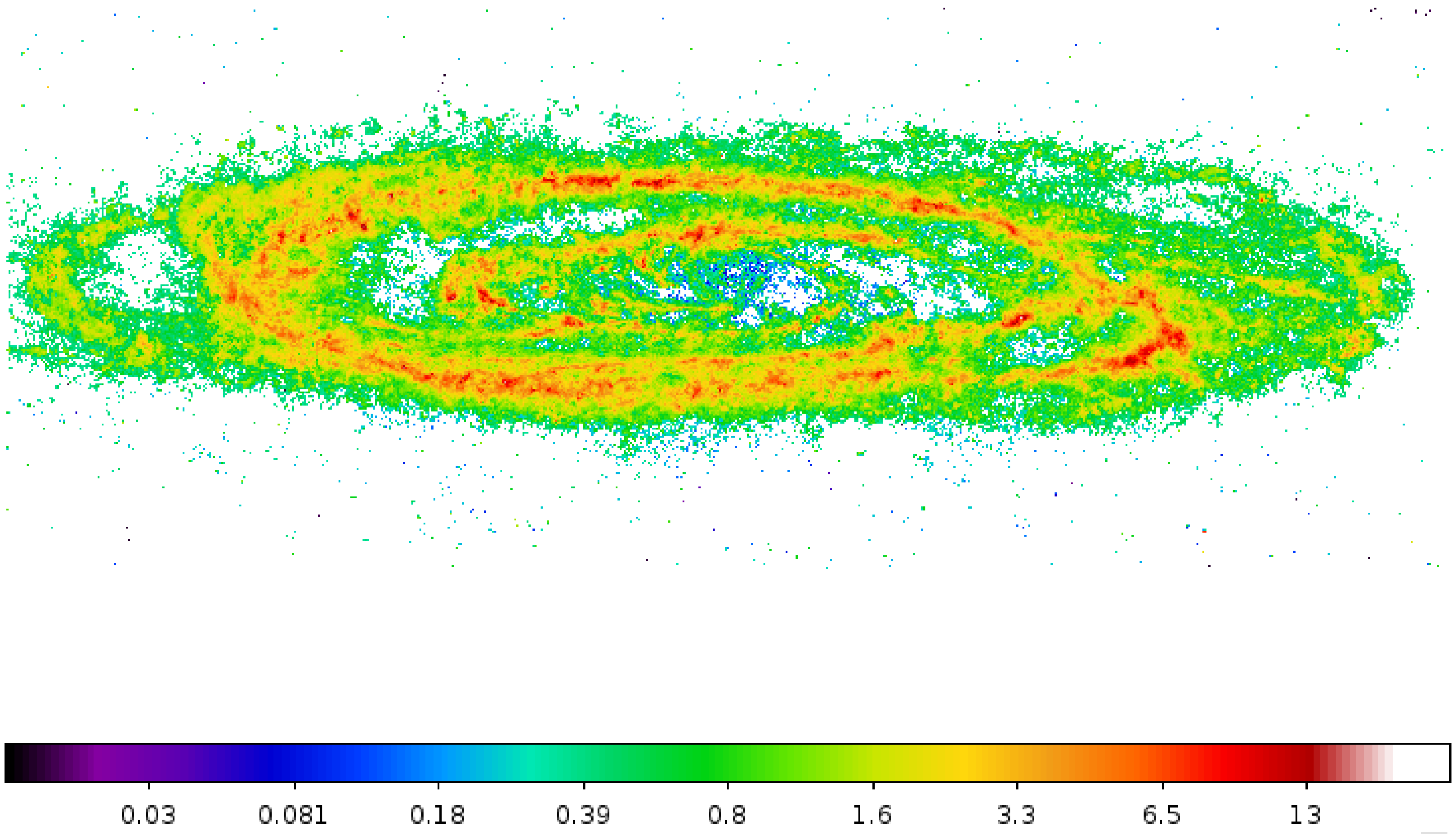

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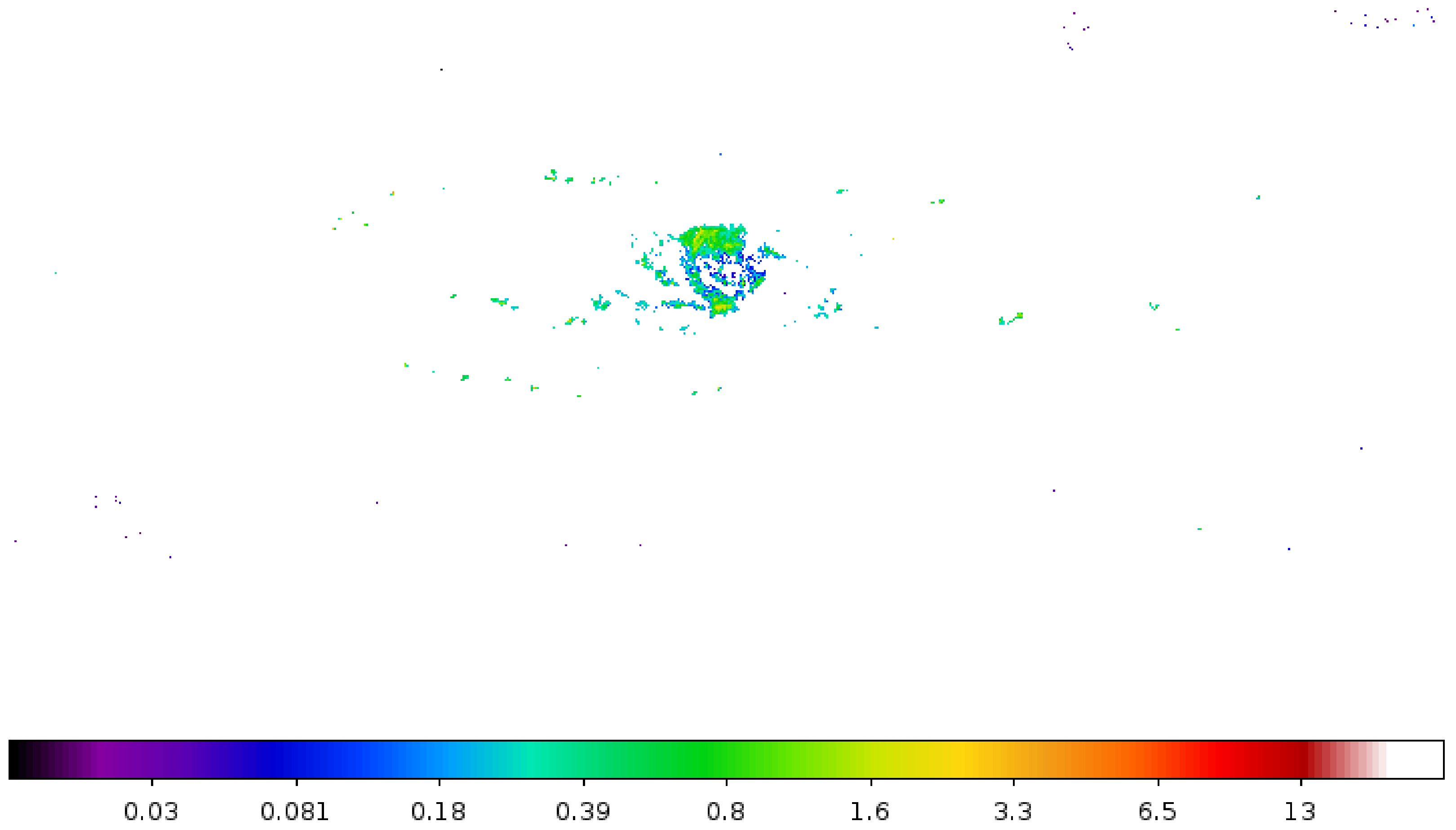
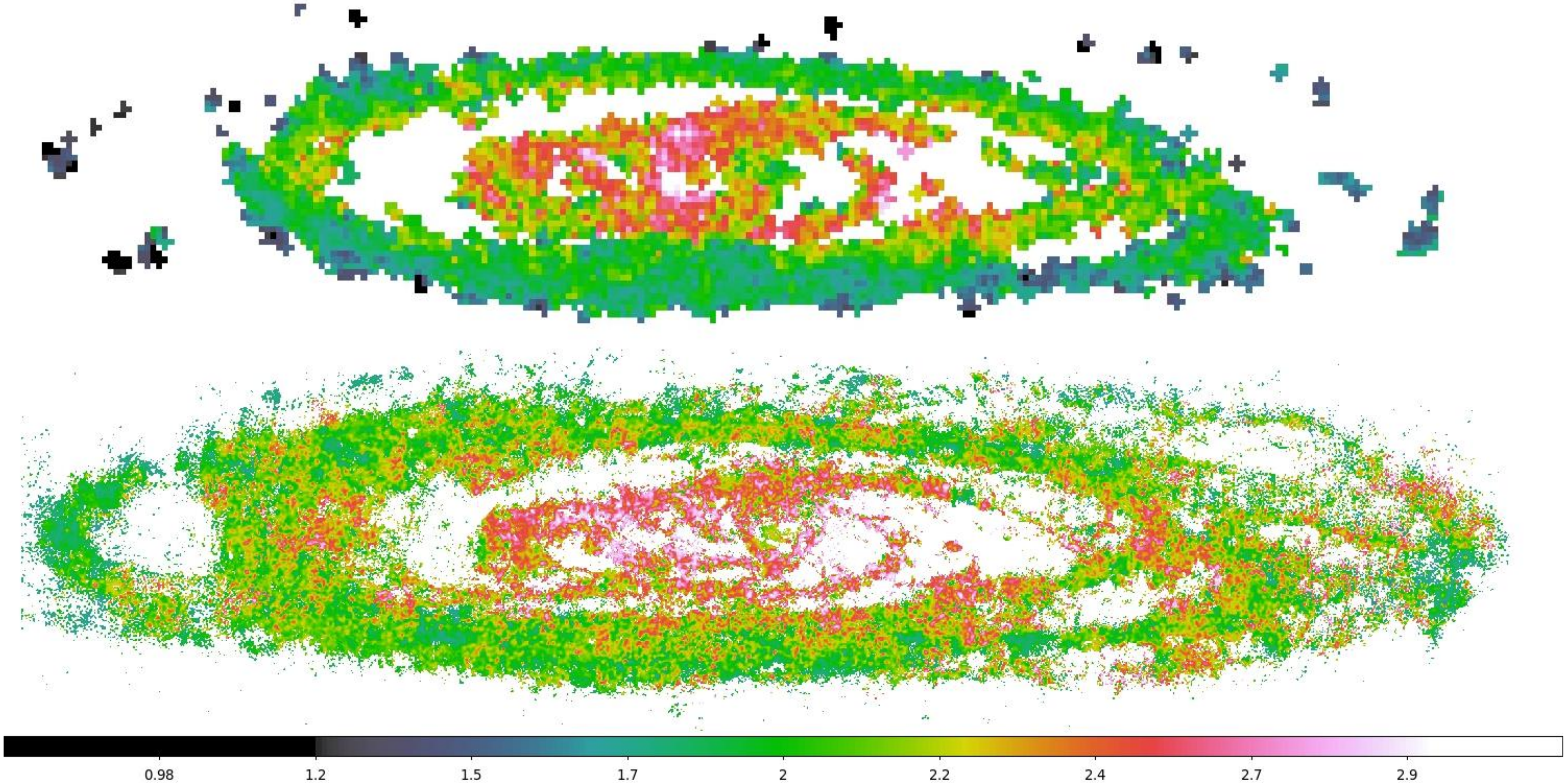
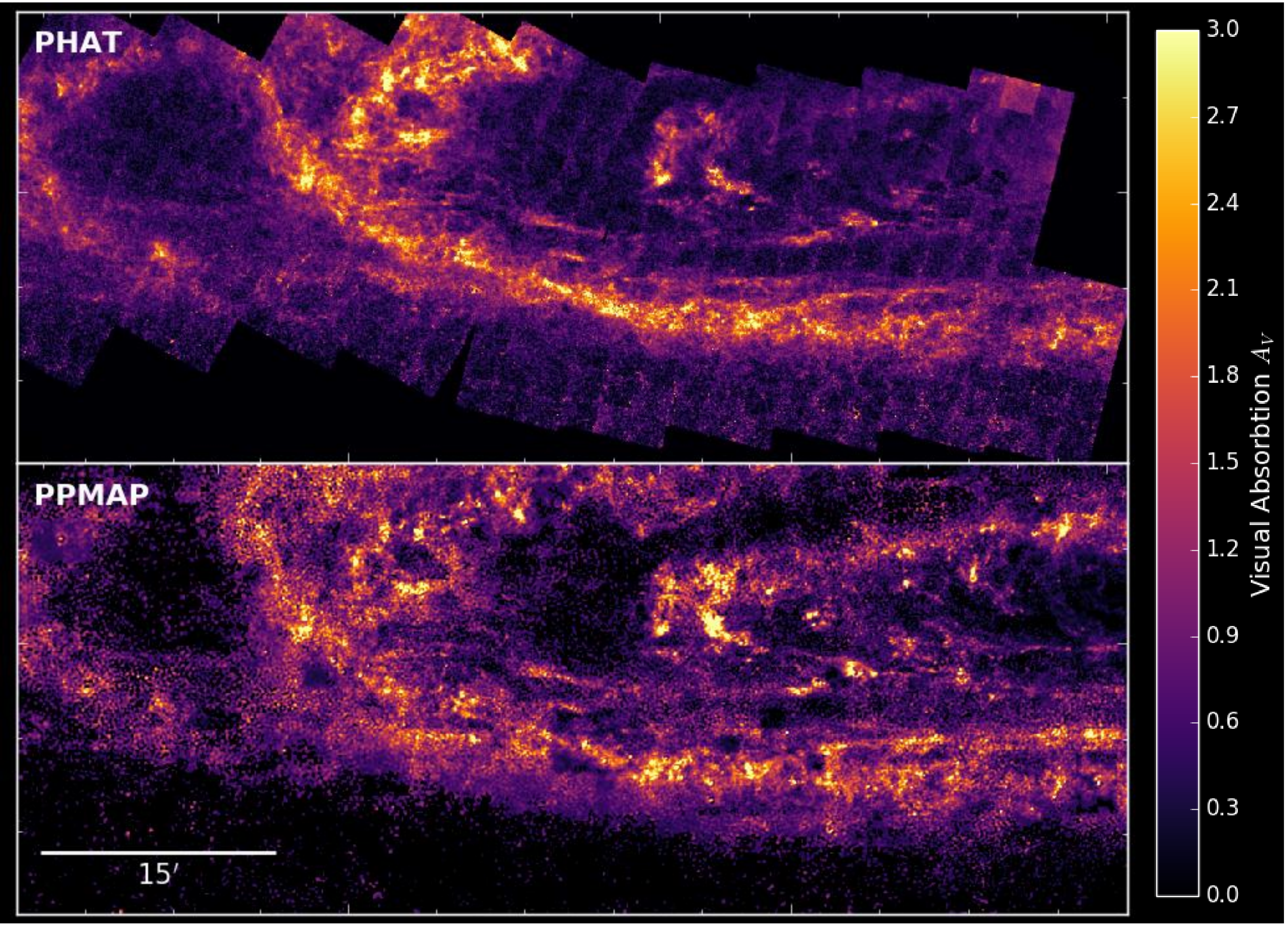


PPMAP – Mass-weighted β



PHAT vs PPMAP (Whitworth et al. submitted)



- Have a good overall agreement between optical extinction and dust emission

HARP and SCUBA-2 HI-resolution Terahertz Andromeda Galaxy survey (HASHTAG)

JCMT 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.

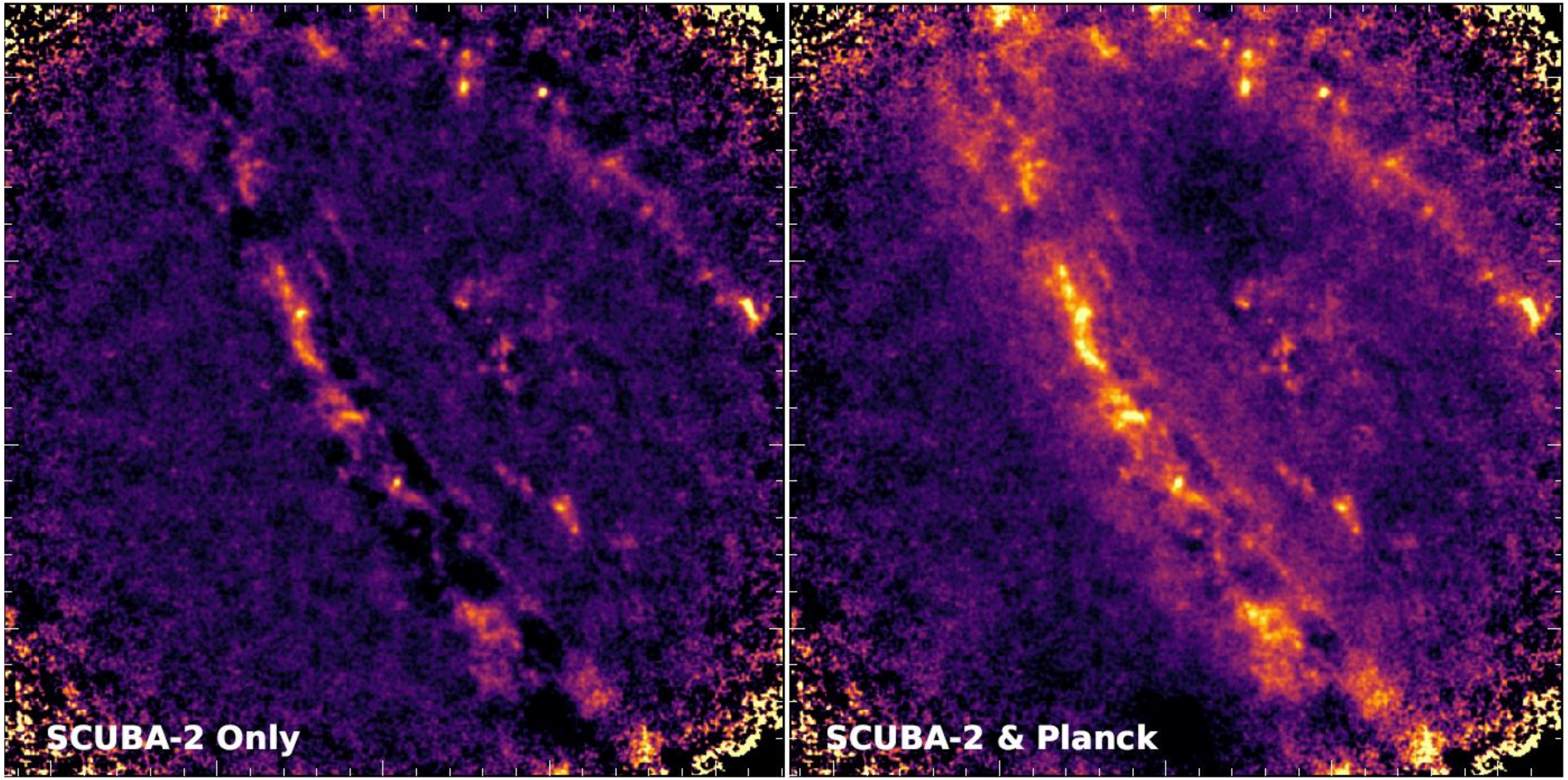
- 25pc resolution, expecting ~2000 clouds with $> 10^3 M_\odot$

But what about problems SCUBA-2 and extended structure?

Large Scale Structure – Pilot Data

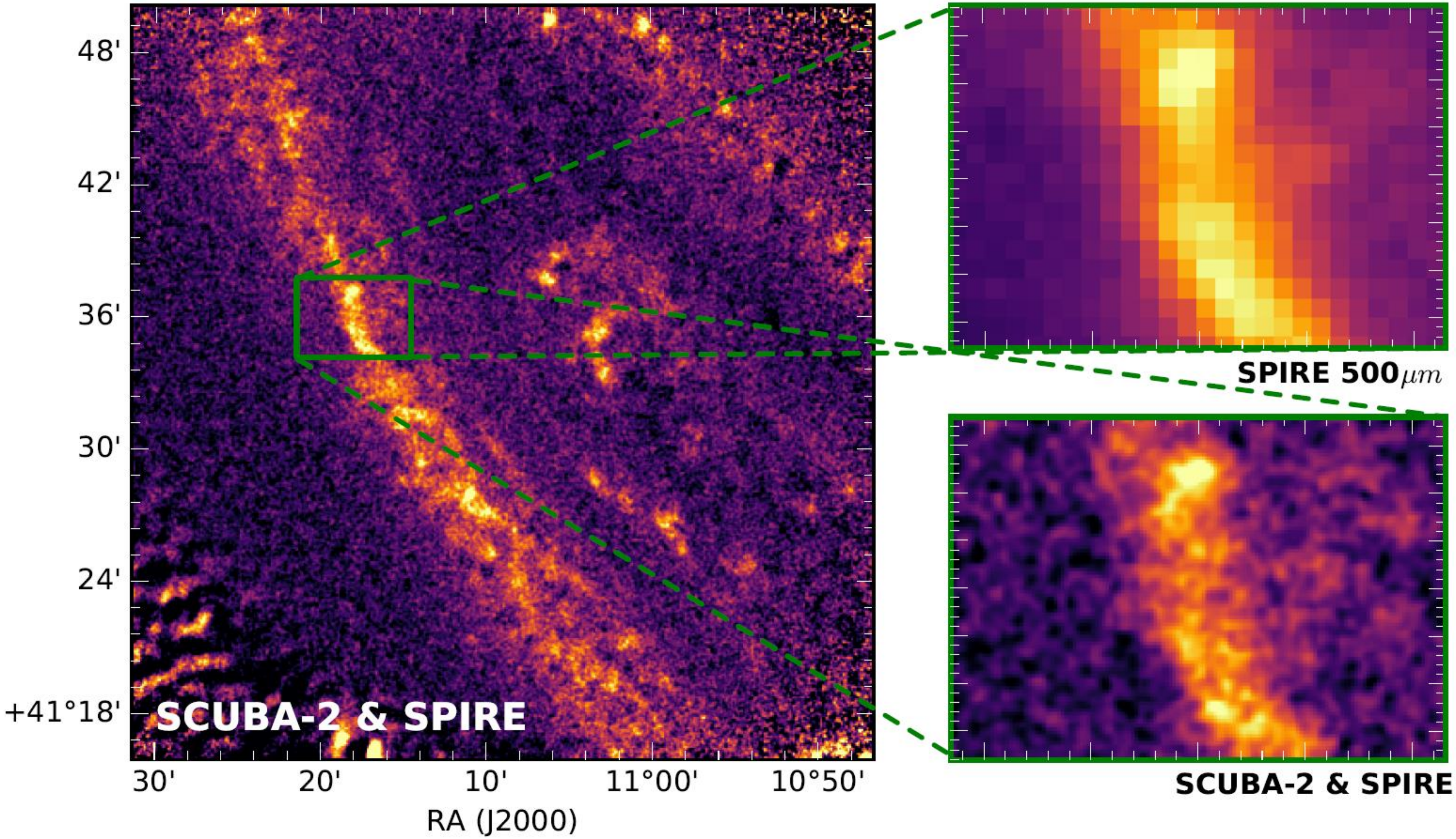
- SCUBA-2 uses filtering in the DR, set too light instrumental noise dominates, too harsh remove emission

- Had the idea to borrow from radio and use Planck 870µm to recover large scales so can use stronger filter



450μm

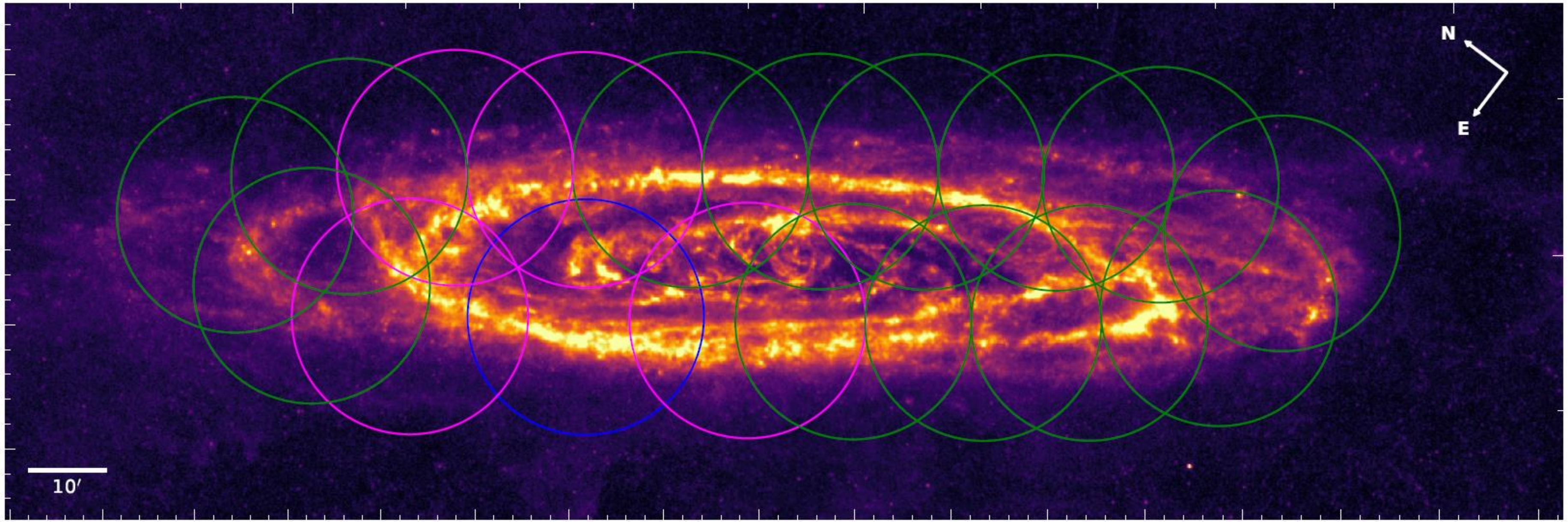
- At 450μm we use the SPIRE 500μm emission to recover the large scale emission



HASHTAG – Current Status

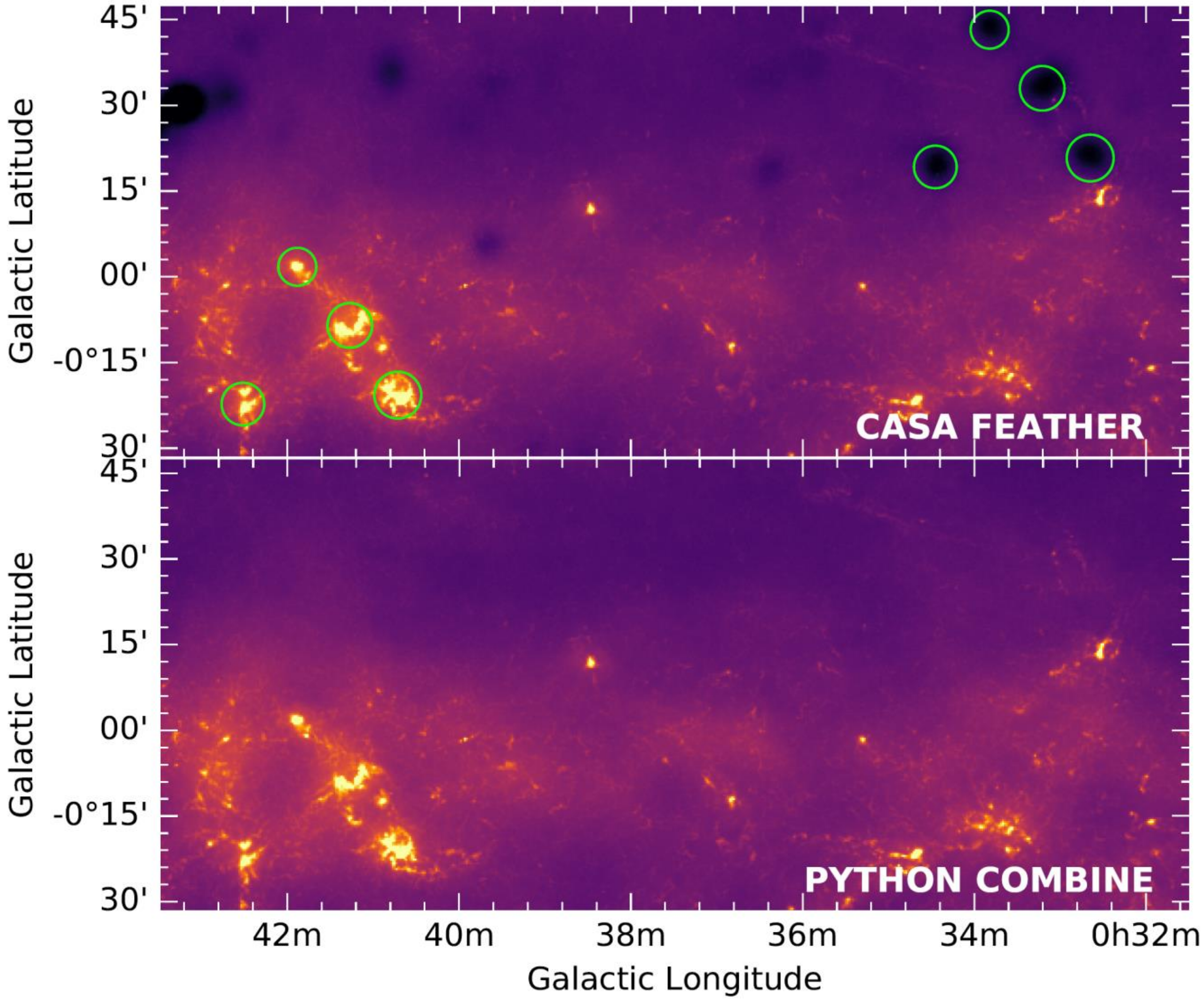
JCMT Andromeda Galaxy Survey

- SCUBA-2 data now 25% complete
- Original plan (to allow for transients), observe half of each pointing then repeat
- Hit by the bad winter weather last year
- 2018/19 year enough time passed so changed to get full depth on the Hubble PHAT region, so can write Hubble comparison papers



HASHTAG – Software

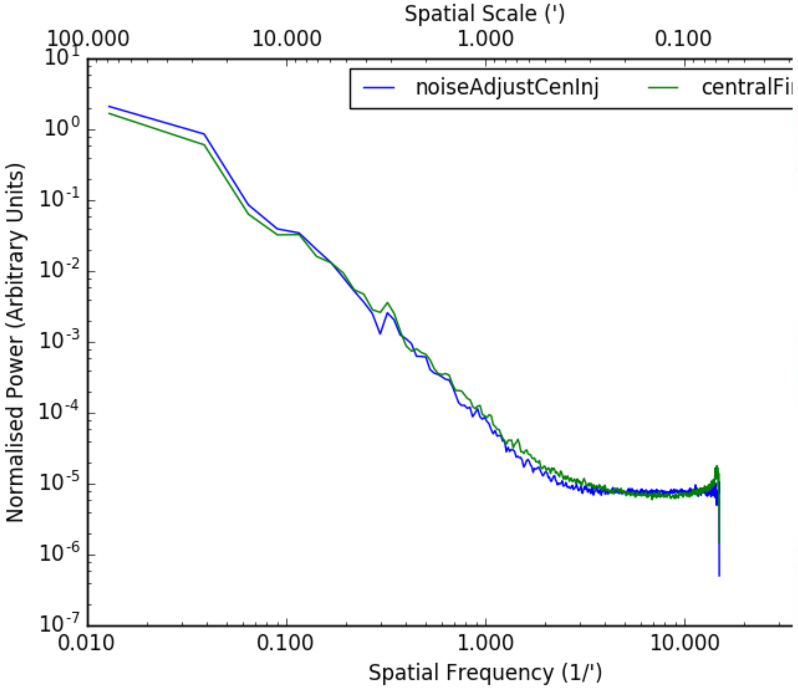
- Unique data challenge
- Returned skyloop factor of 2 faster (disclaimer on measured our system)
- Python Large Scale recovery script – will be released soon

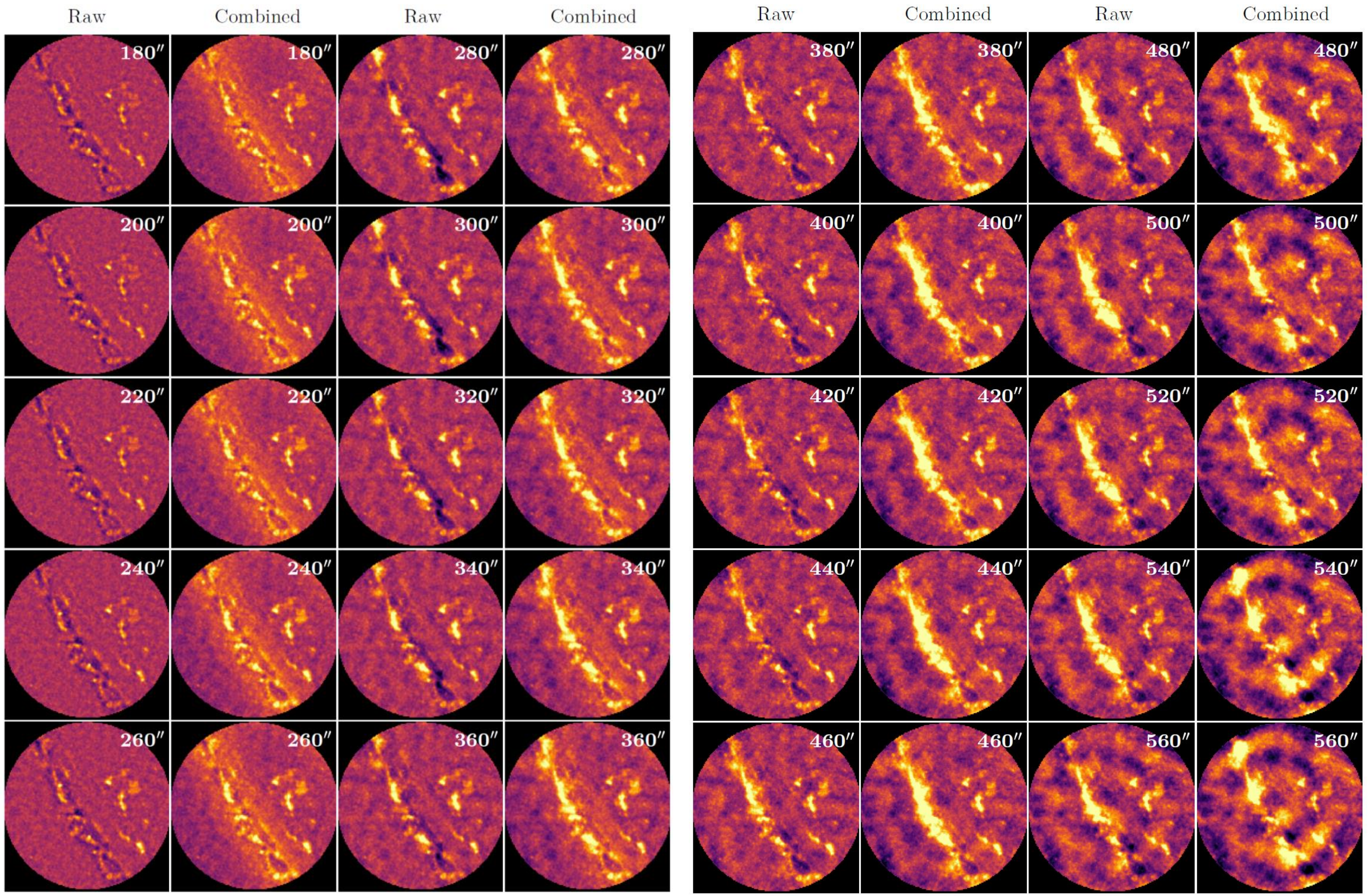


HASHTAG – Software

JCMT Andromeda Galaxy Survey HASHTAG

- Many Simulations!

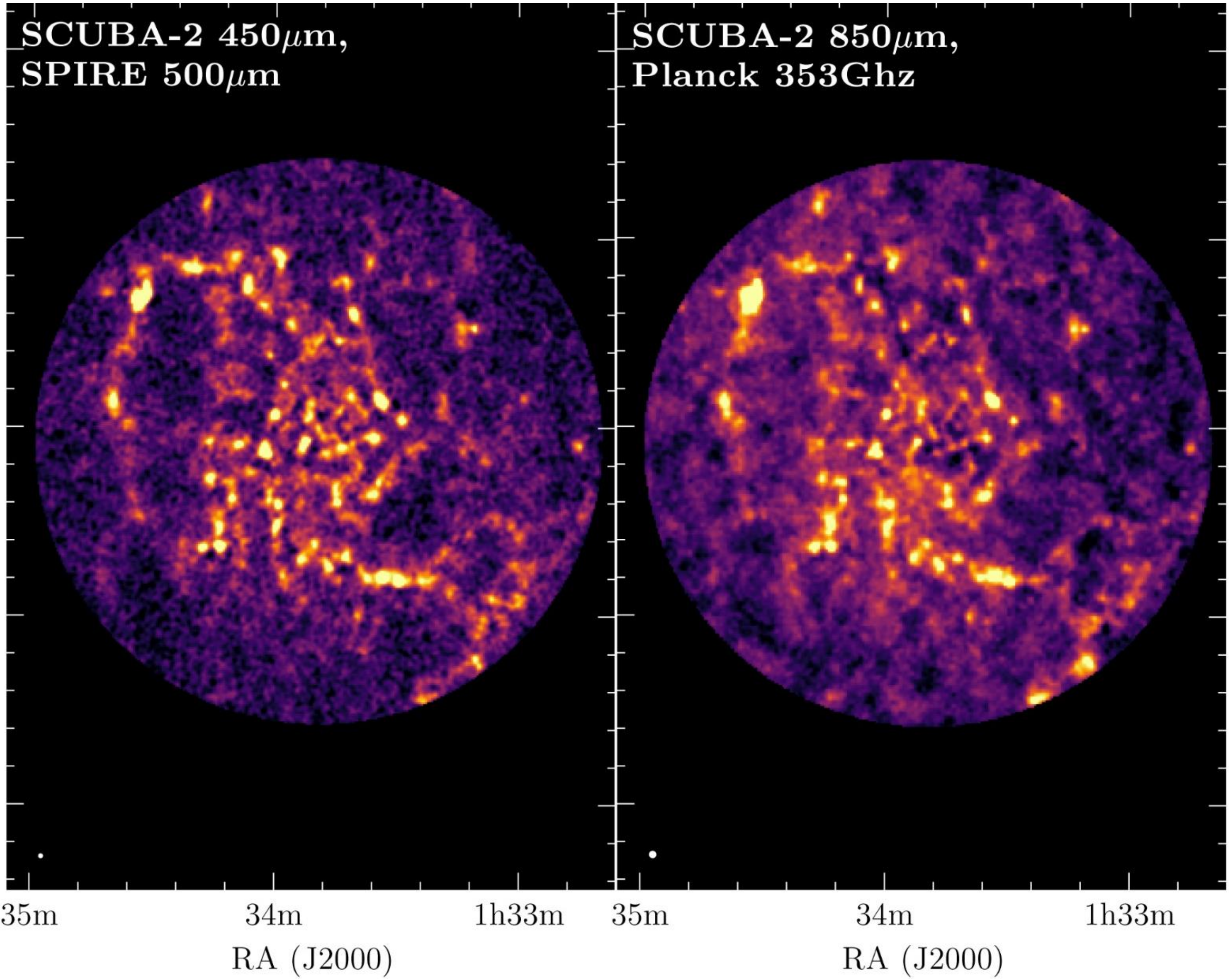




HASHTAG – some science goals

- 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?



- Tom Williams (Williams et al. submitted)
- Performed SKIRT radiative transfer on M33
- Dust energy balance seems to work on 1.5kpc scales
- Agrees with other works that suggest

Need for FIR/ Selection Effects

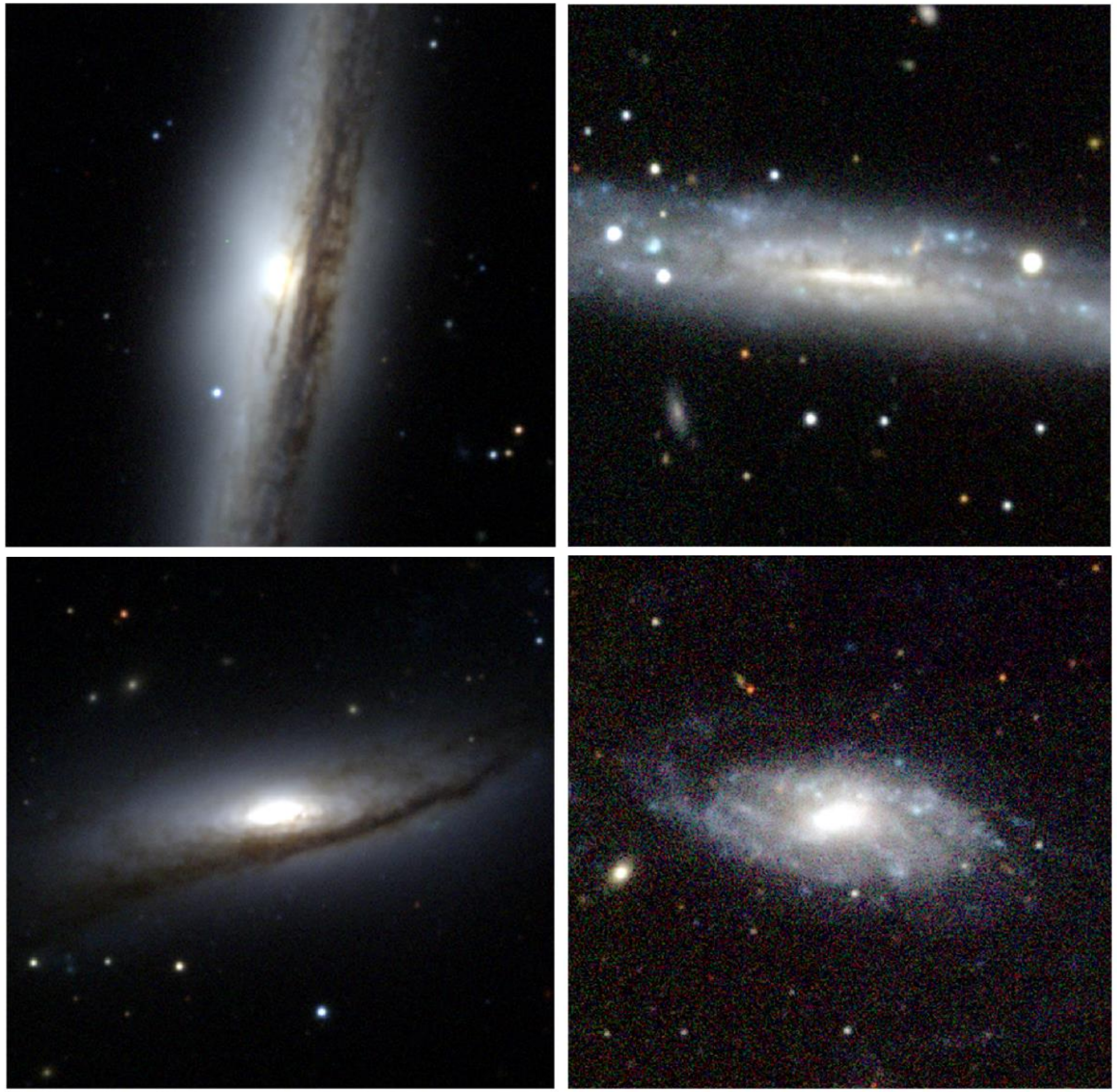
- ▸ Badgers
- ▸ Contain <5% of the stellar mass but >35% of the dust mass.

1. Blue but dusty
2. Cold dust T, but high SFR
3. Very atomic gas rich, but molecular poor
4. Tend to be flocculent

- ▸ Possibly a low-z analogue to high-z objects

Clark et al, 2015

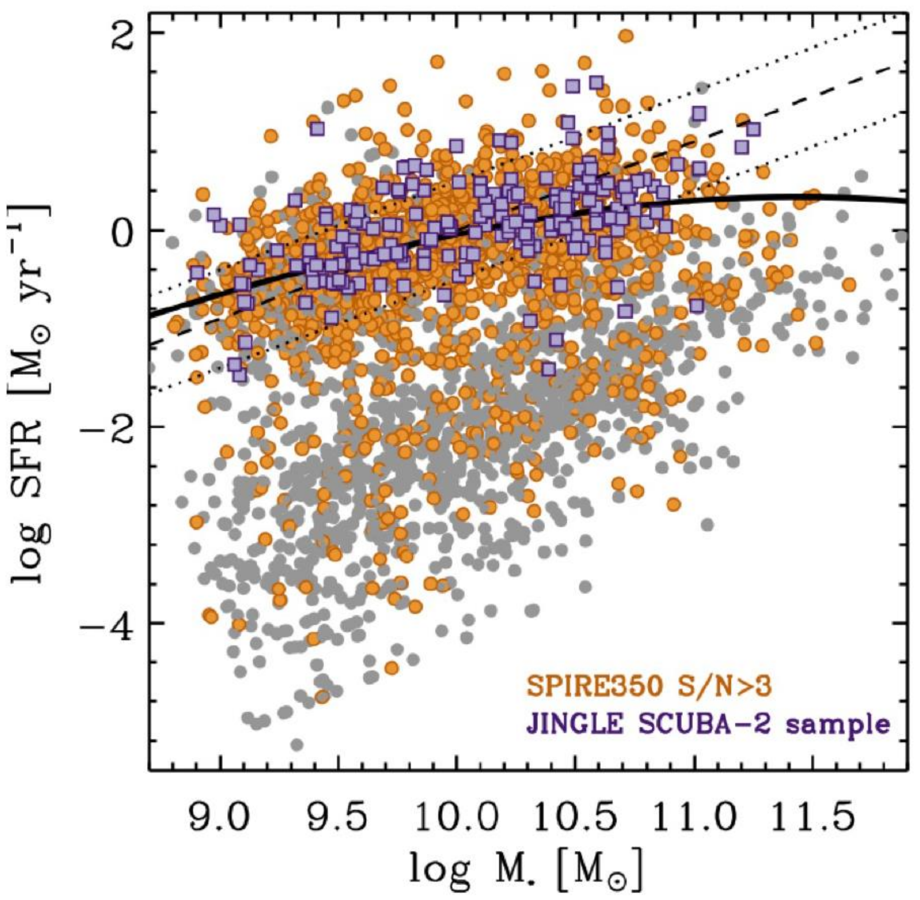
Dust Lanes ≠ Dust Rich



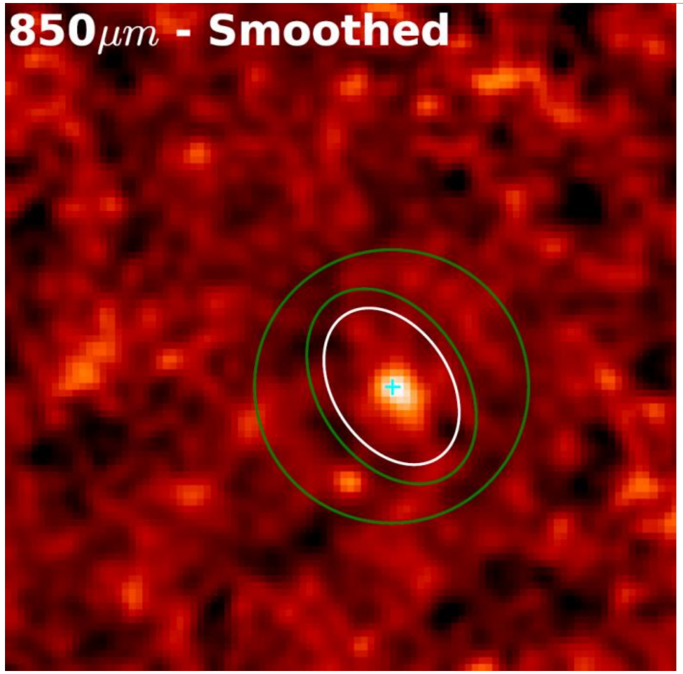
$M_D/M_S \sim 0.0005$ $M_D/M_S \sim 0.01$

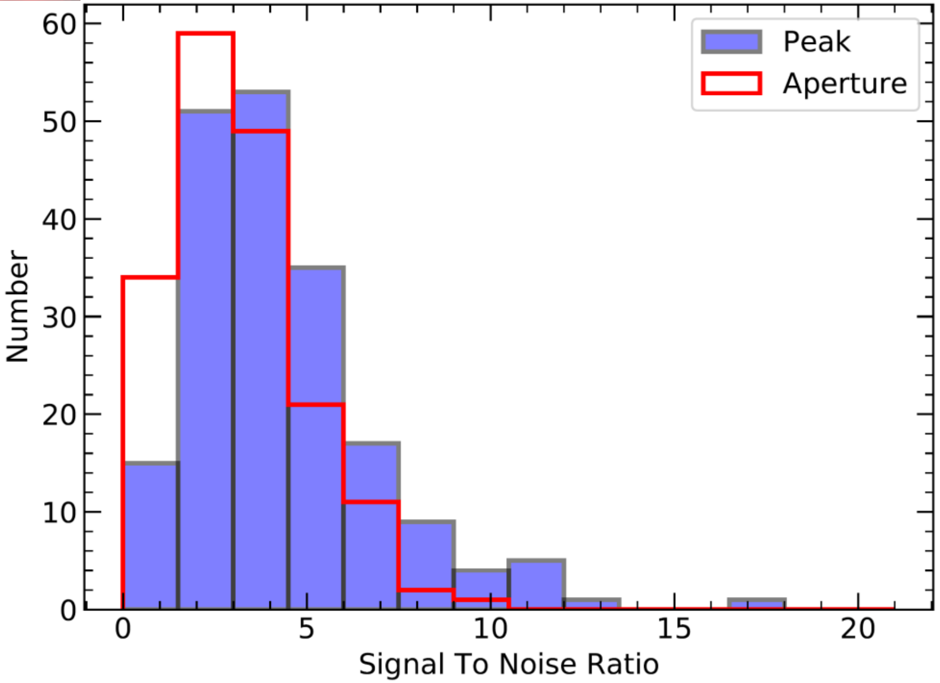
JINGLE – the JCMT legacy of dust and gas in Nearby Galaxies Exploration

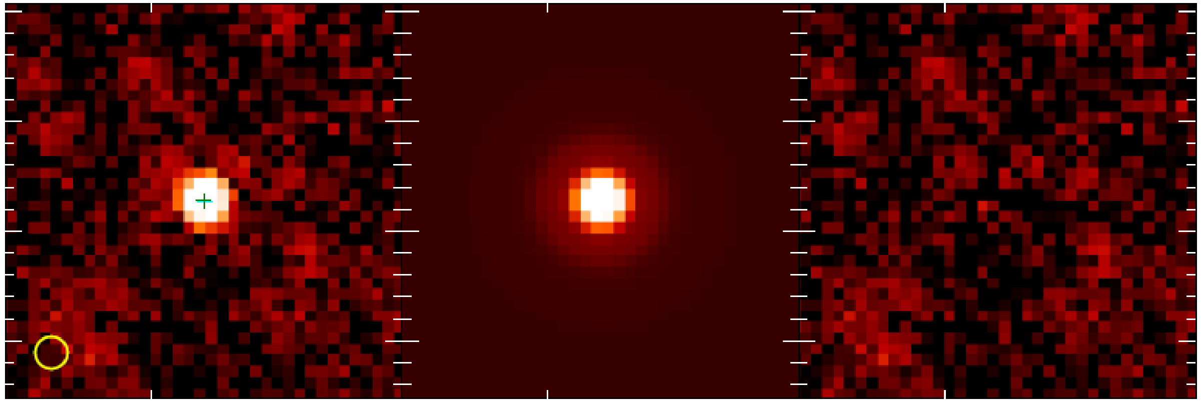
- Designed to bridge gap of limited overlap between dust and CO surveys
- 193 galaxies 41-212 Mpc with SCUBA-2 from H-ATLAS designed so galaxies are very extended
- 90+ galaxies with CO(*J*=2-1)
- Will also be MaNGA
- Have also a HI for whole sample
- JINGLE II extension for starbursts & green valley targets
- JINGLE paper I (Saintonge et al. 2018 outlines sample, multi-band photometry, MAGPHYS etc…)



JINGLE II – Published last month (Smith et al. 2019)



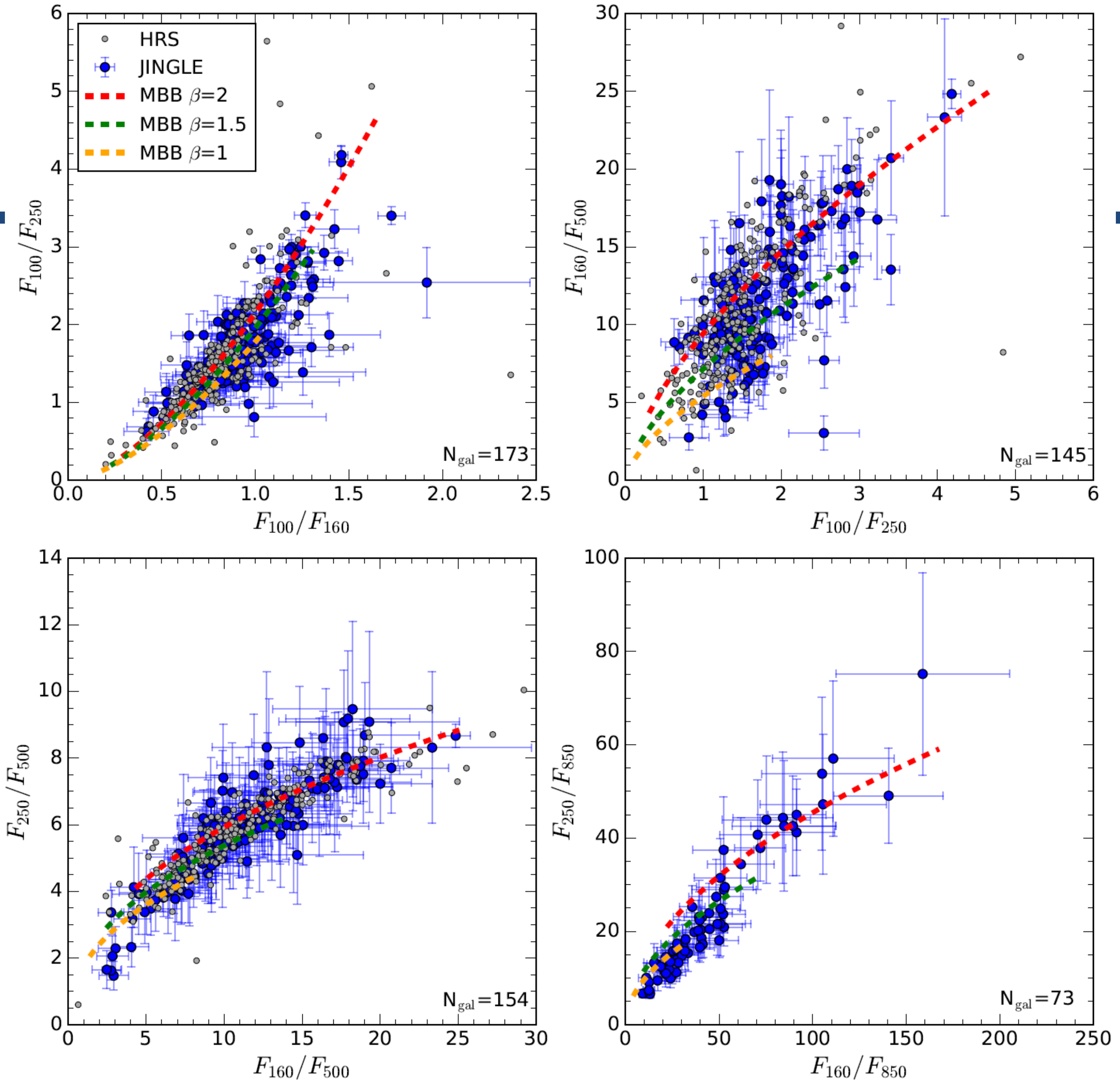




- Presents all the 850μm SCUBA-2 data
- Lot of very detailed ways to optimise the SCUBA-2 reduction (10+ pages)
  - Optimised masks/reduction parameters
  - Modified calibration
  - Simulations injected all galaxies into blank data
- Complete set of dust matched aperture measurements

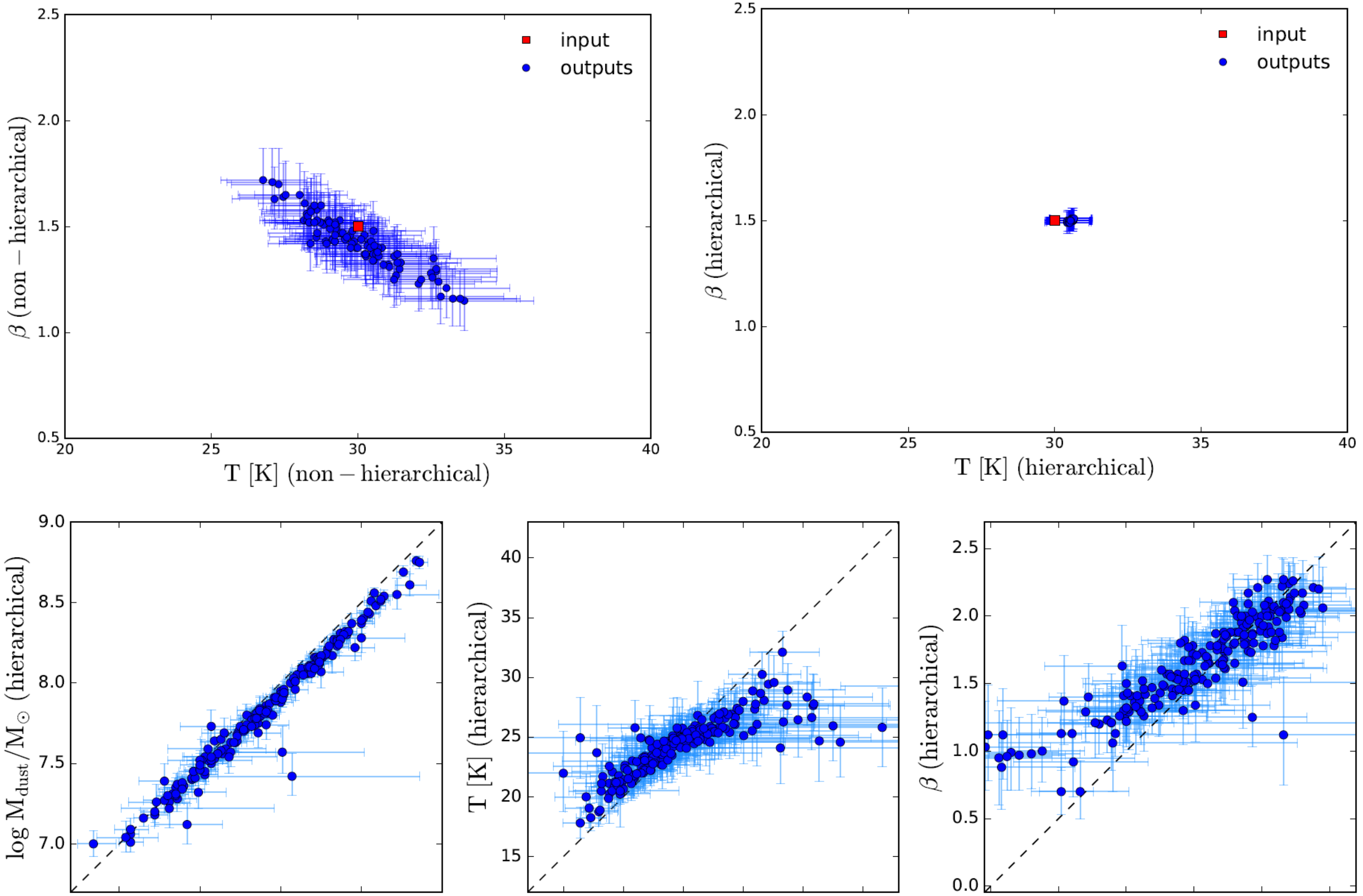
JINGLE II – Results

- S/N a struggle for a lot of objects
- Data inconsistent with 1TMBB
- 2TMBB does not seem to explain
- Broken dust emissivity law at ~500µm can provide a better fit



JINGLE Paper V (or maybe III) – Lamperti et al.

- Fits hierarchical Bayesian models to the data
- β correlates with surface mass density and metallicity
- Dust T correlates strongly with dust temperature per unit mass
- 26/192 galaxies have signs of a sub-mm excess

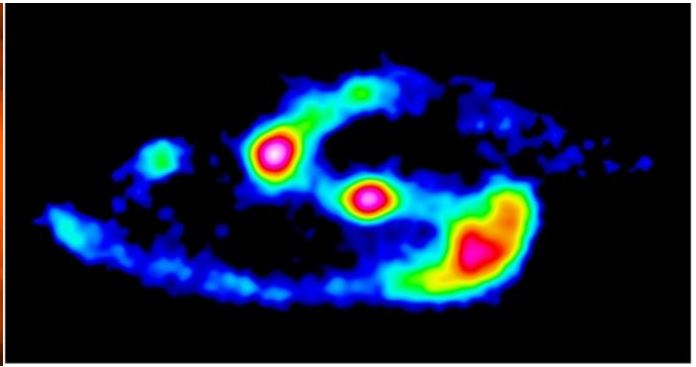


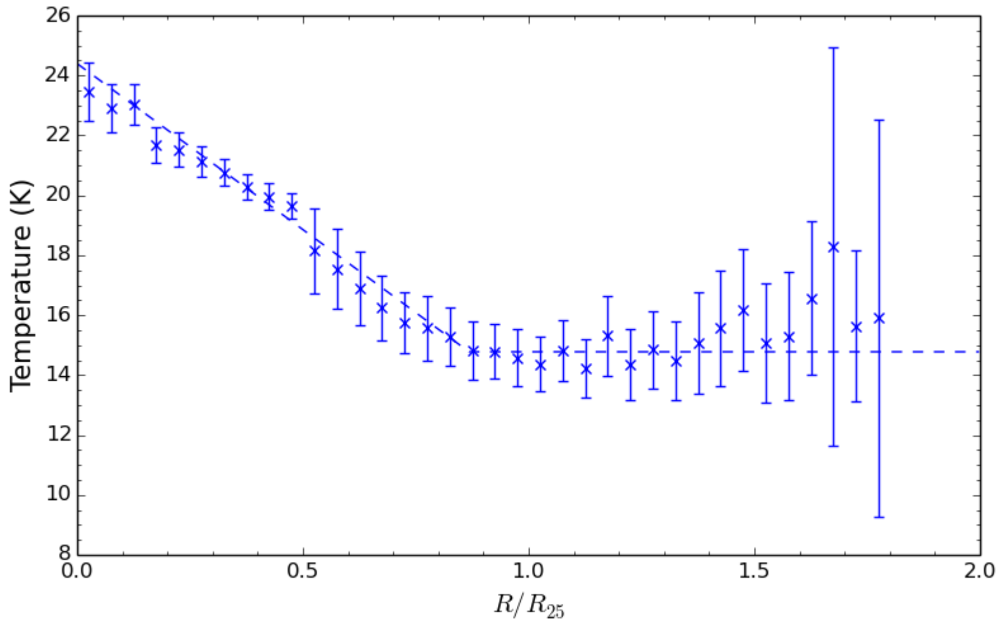
Nearby Galaxies Future Projects

- For large resolved nearby galaxies, problem has been preserving faint large scale emission – particularly in grade 3+ weather
- With stability of KIDS and larger FOV hopefully be able to preserve larger scales.
- For these large scales 850µm great for dust modelling side, but really would want the resolution at 450µm to resolve GMC complexes
- Faint dust in the outskirts of galaxies

SPIRE 250µm

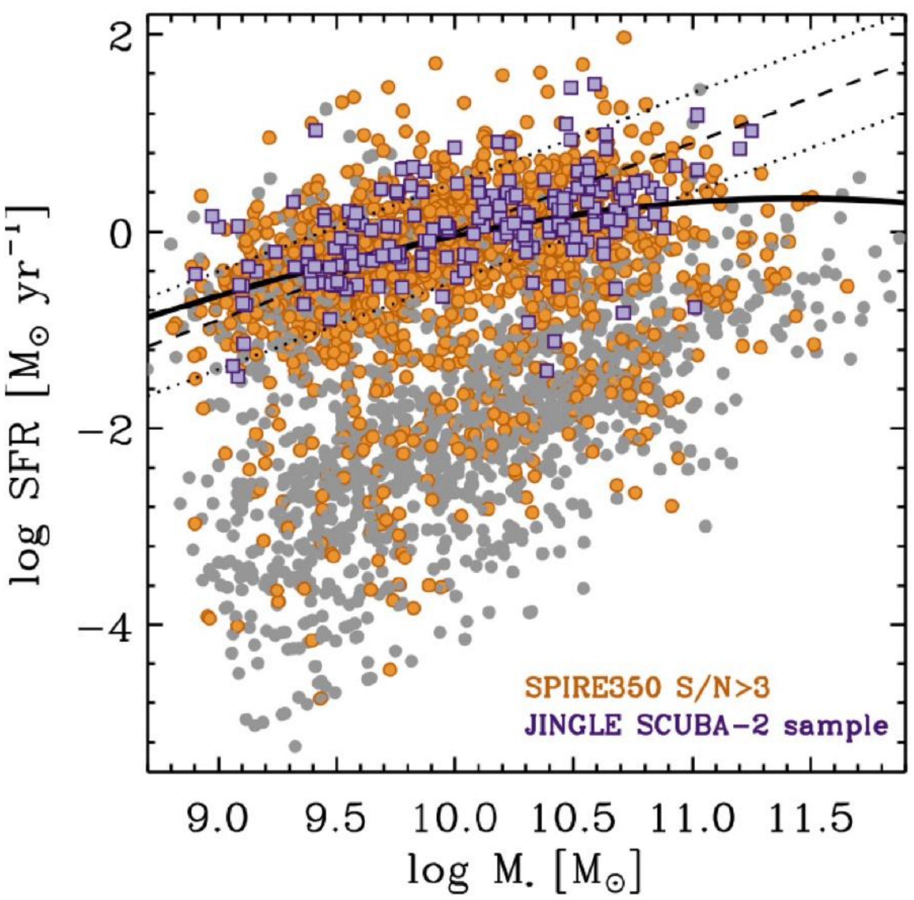
SCUBA2 850µm



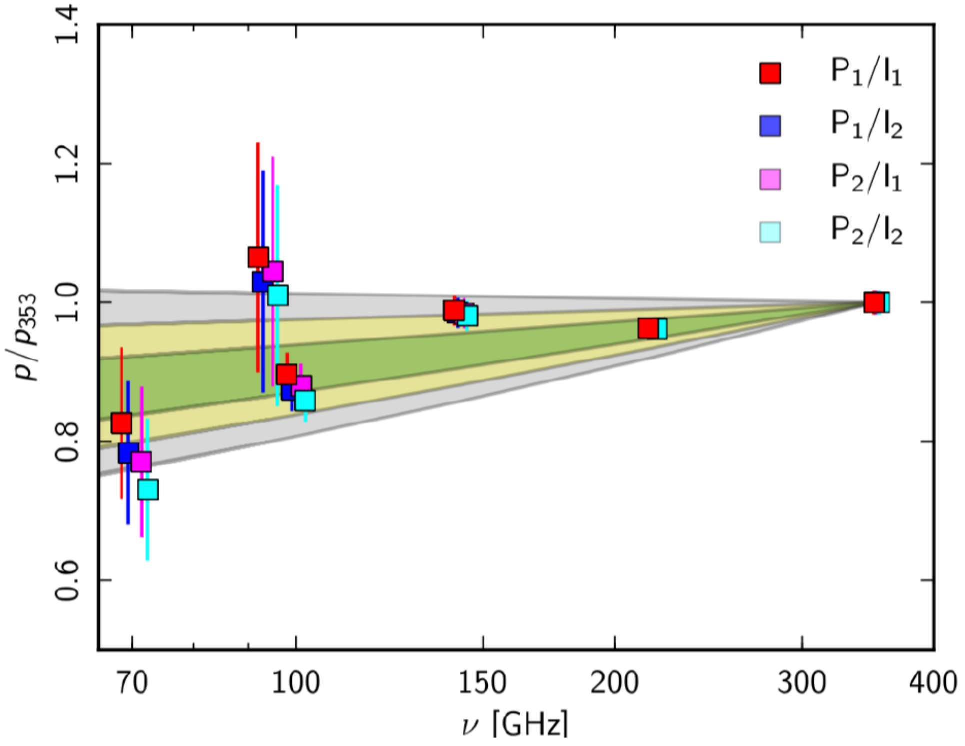


Nearby Galaxies Future Projects

- More sensitive representative surveys at 850μm would allow us to sample much bigger variety in:
  - Specific star-formation rate
  - Metallicity
  - Stellar mass
  - Low-surface brightness objects
- Some galaxies HI/CO will be too hard (like BADGERS)
- Combining with instruments like NIKA/TolTec maybe able to map free-free emission



Nearby Galaxies Future Projects



from Planck Collaboration et al. (2015)

- Bruce Draine always asking me about dust polarisation.
- With a 10x increase in mapping speed, it maybe measurable in galaxies
- Is the dust like the what we see in local neighbourhood of the Milky Way
- Personally I think 850µm is the right decision, but with NIKA and Toltec surveys I think 450µm will become more important in subsequent years

Conclusions

- Thank you for listening
- New members HASHTAG welcome!
- Need a new coordinator in Taiwan