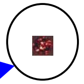
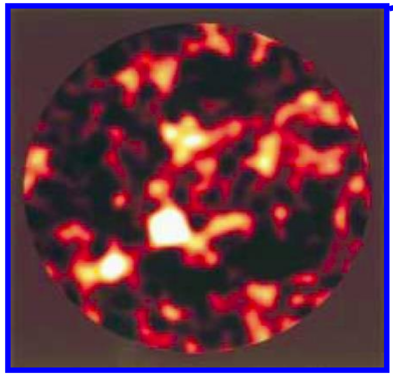
Dust as a tracer in the Milky Way and local galaxies

Matthew Smith

Dust as a Tracer

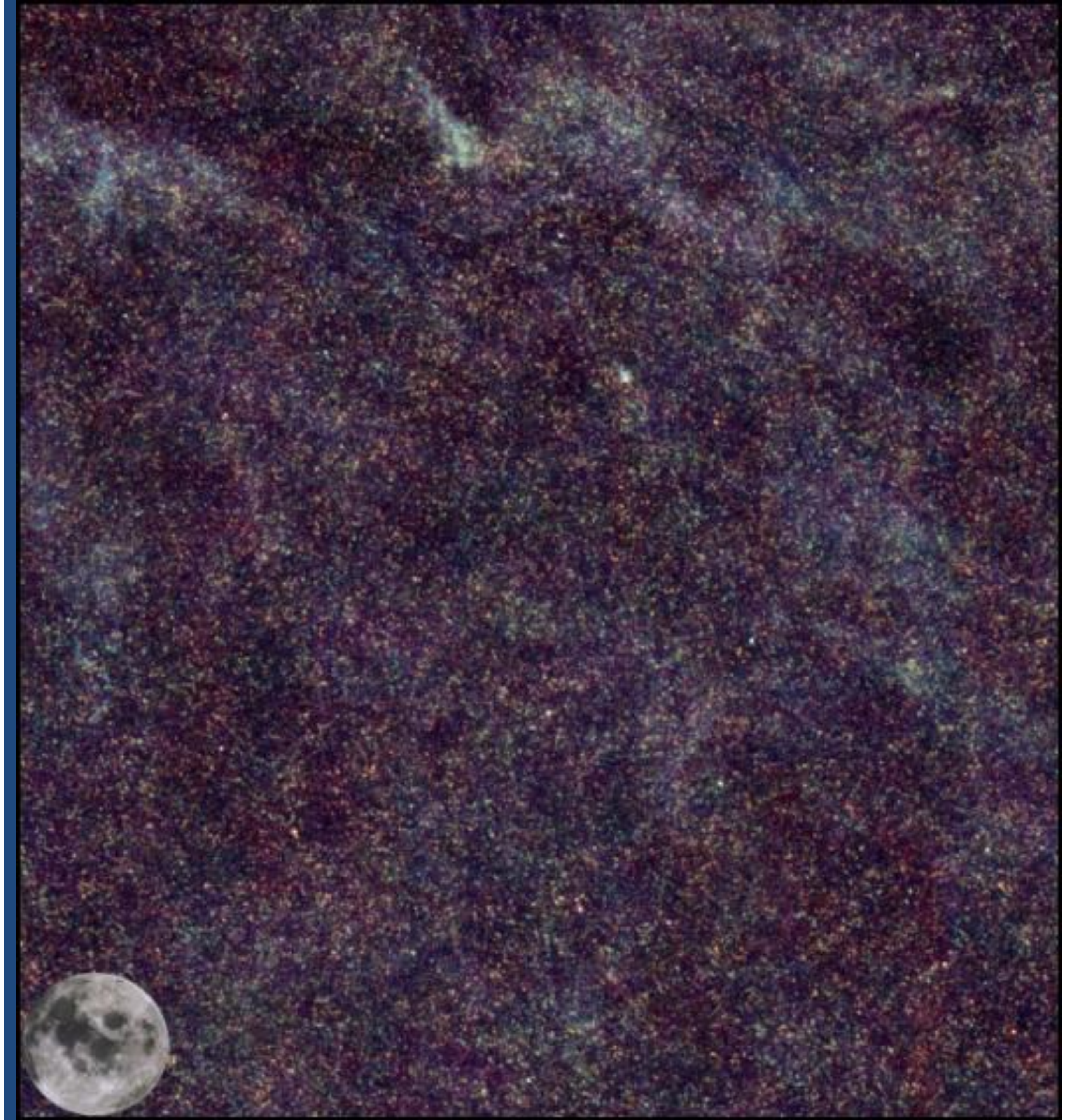
1998 Ground-based
5 galaxies after 20 nights





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

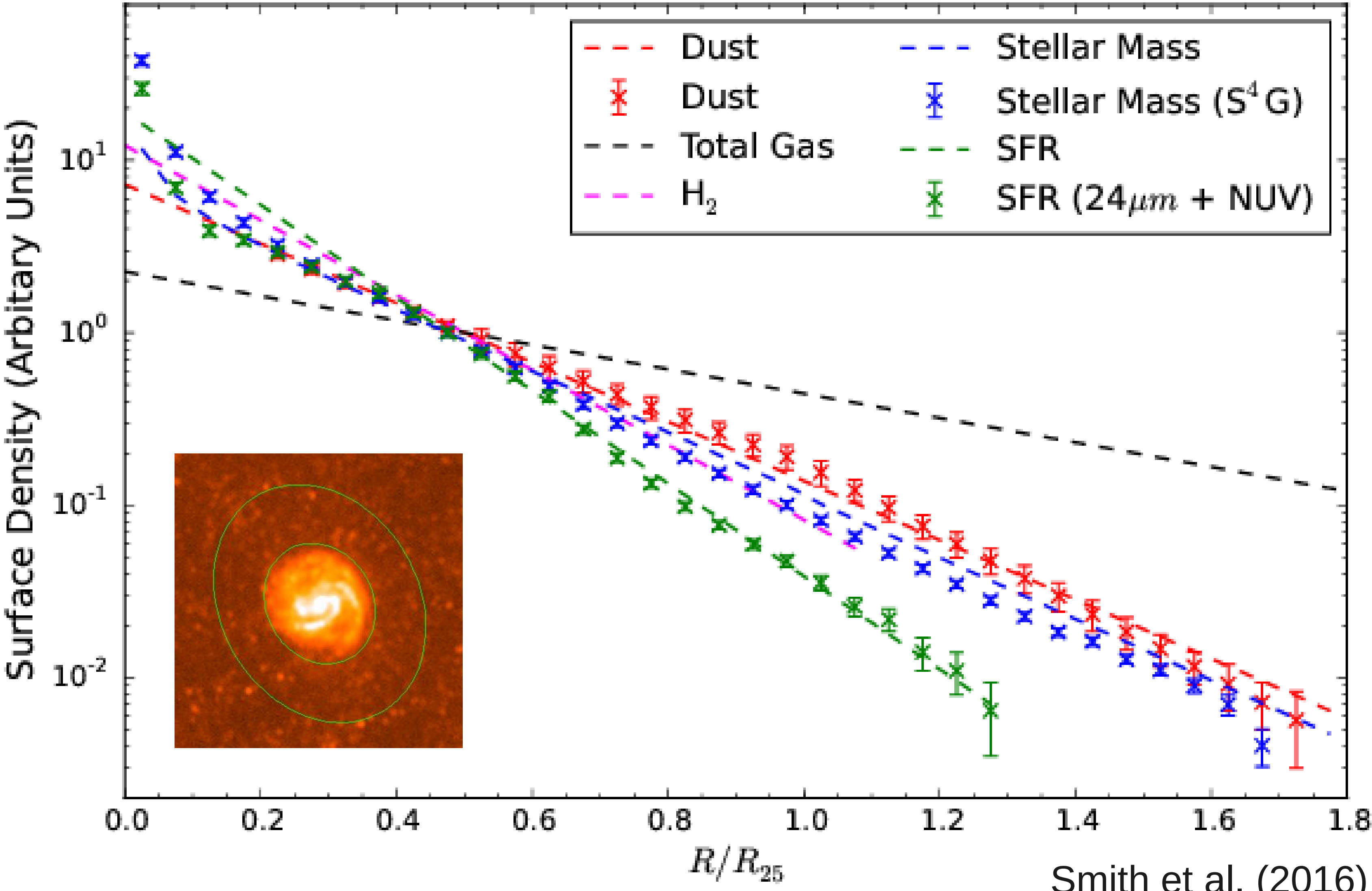
Poster by Rosie #164
New local dust mass function (Beeston et al. 2018)

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

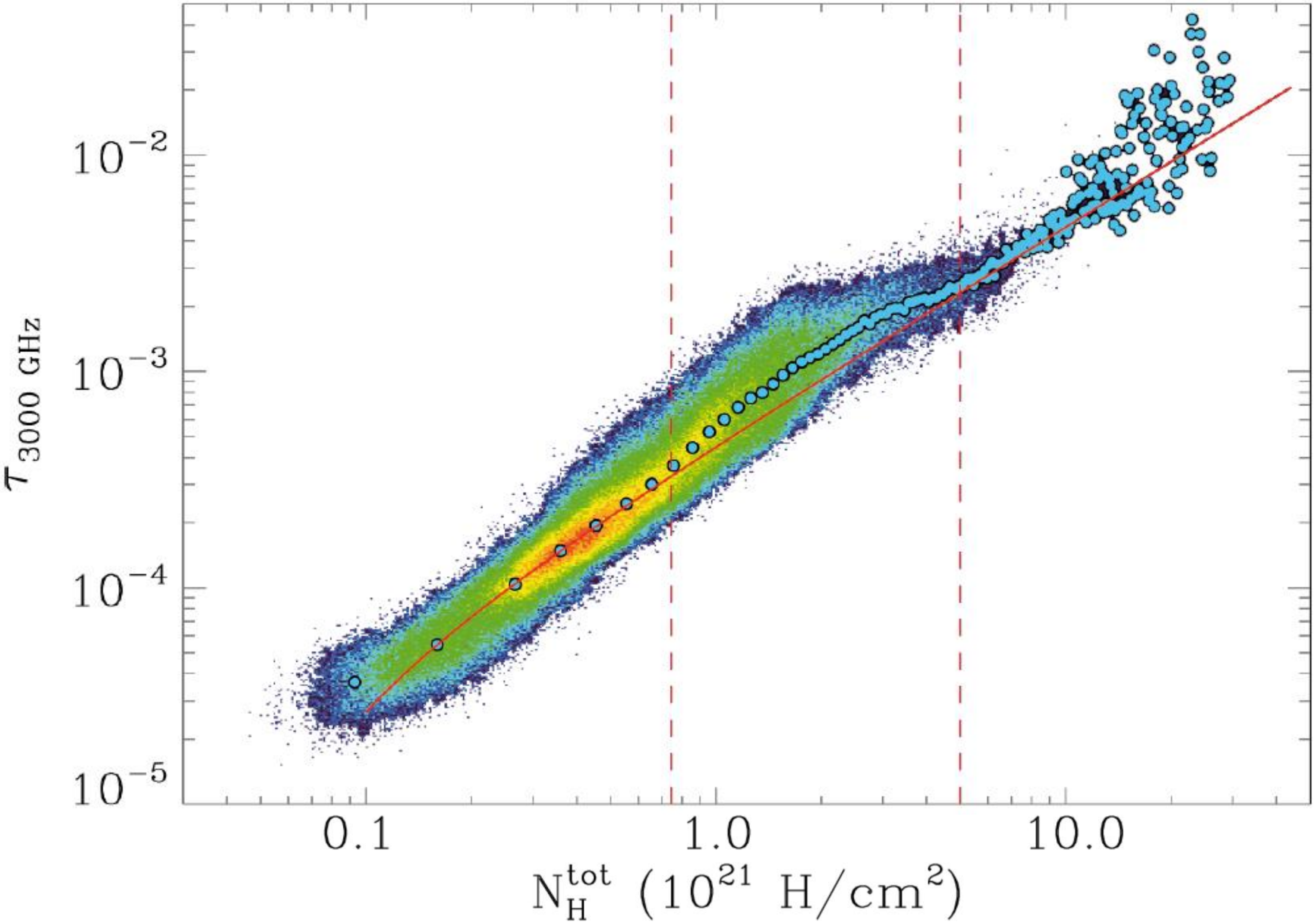
Holwerda (2009)



Smith et al. (2016)

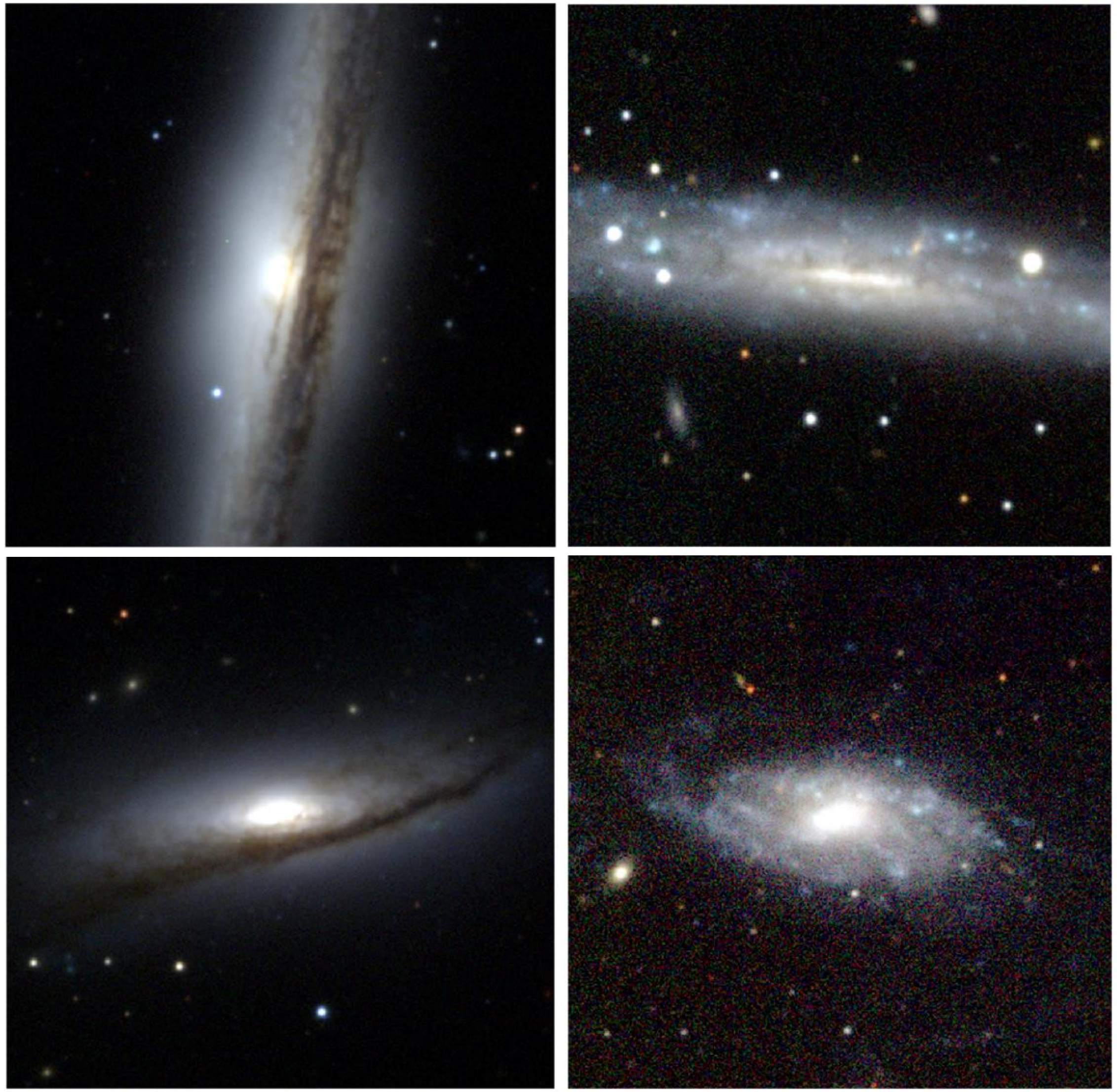
Planck – Dark Gas (2011)

- We know CO is not a perfect tracer, with X-factor varying with metallicity, dissociation etc…
- $\tau = \left(\frac{\tau_d}{N_H}\right)^{ref} \cdot N_H^{obs} + con$
- Dark gas → 28% of atomic gas, 118% of H_2
- Average X-factor 2.54



Dust Has Its Problems

- Dust opacities are uncertain
- Exact size distribution, composition… are unknown
- How reliably can we know gas to dust ratio (metallicity, morphology, etc…)
- To solve these problems – two potential solutions:
  - Need samples that cover a range of all galaxy properties
  - High-resolution studies of objects that cover a range of objects

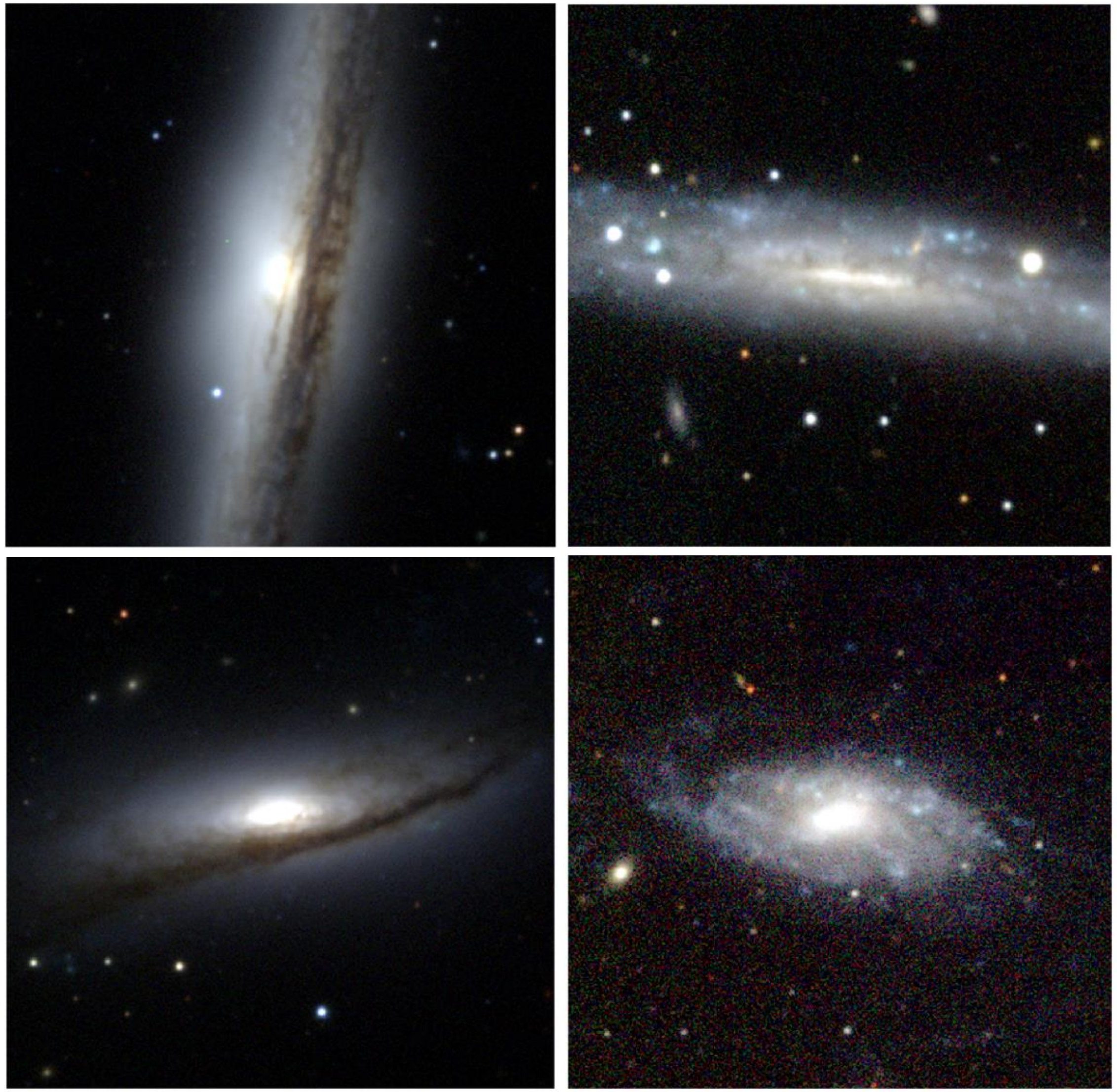


Need for Large Varied Samples

- Some very good optically based samples like HRS
- 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
- JINGLE a new JCMT survey is aiming to resolve issue lack of large representative sample with good dust and CO coverage

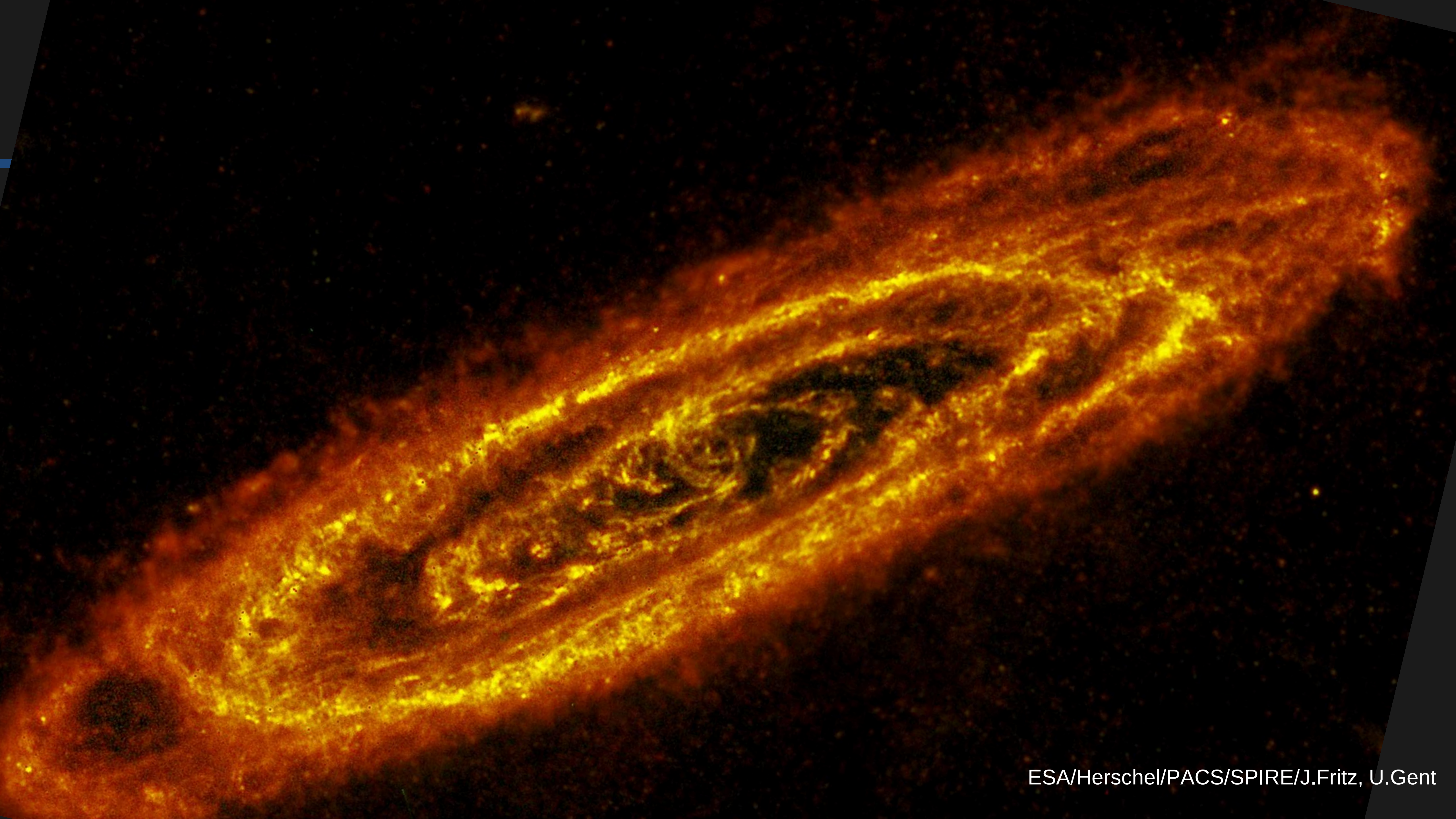
Clark et al, 2015, Dunne et al, 2018

Dust Lanes ≠ Dust Rich

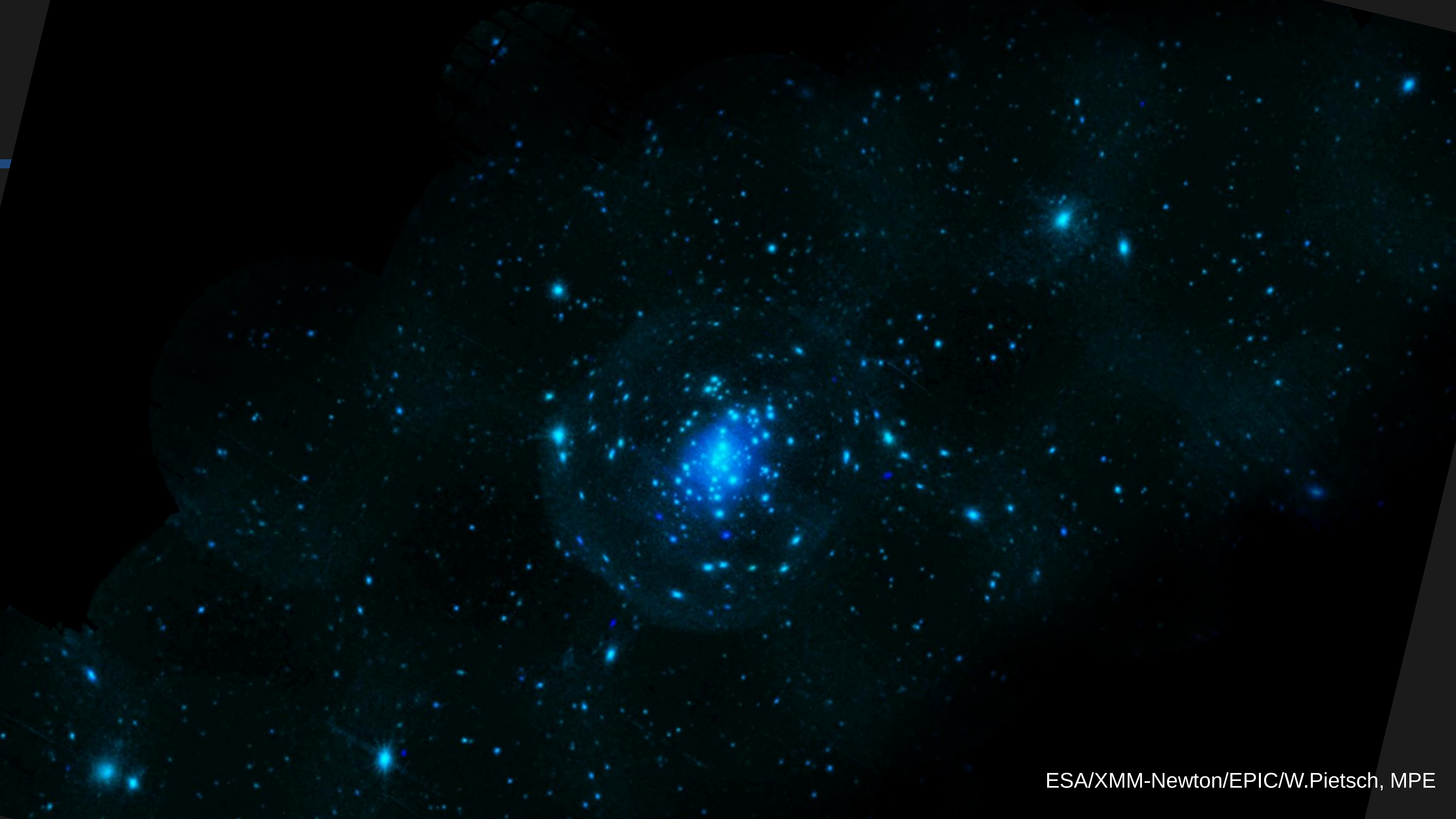


$M_D/M_S \sim 0.0005$ $M_D/M_S \sim 0.01$

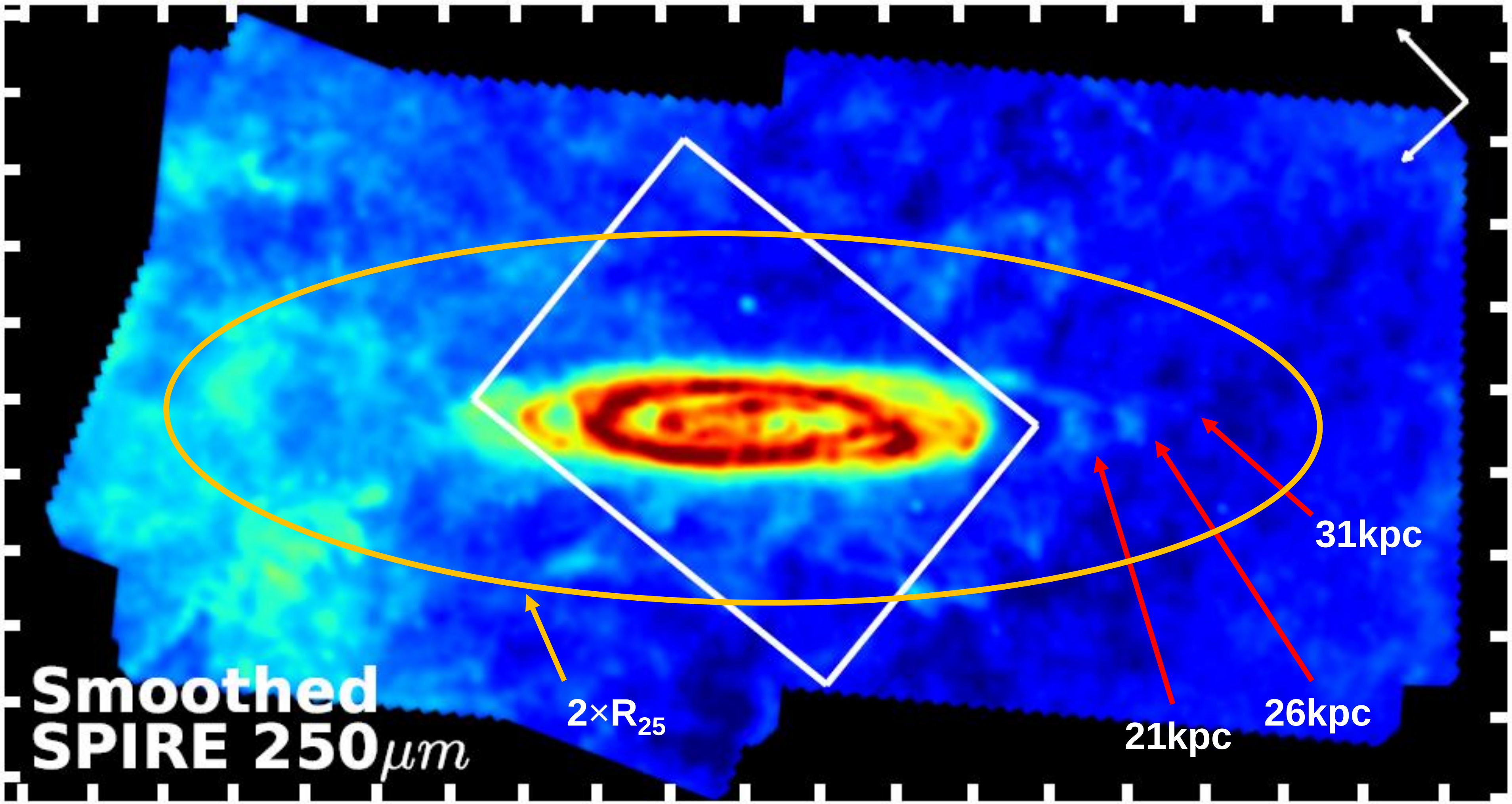

R. Gendler



ESA/Herschel/PACS/SPIRE/J.Fritz, U.Gent


ESA/XMM-Newton/EPIC/W.Pietsch, MPE

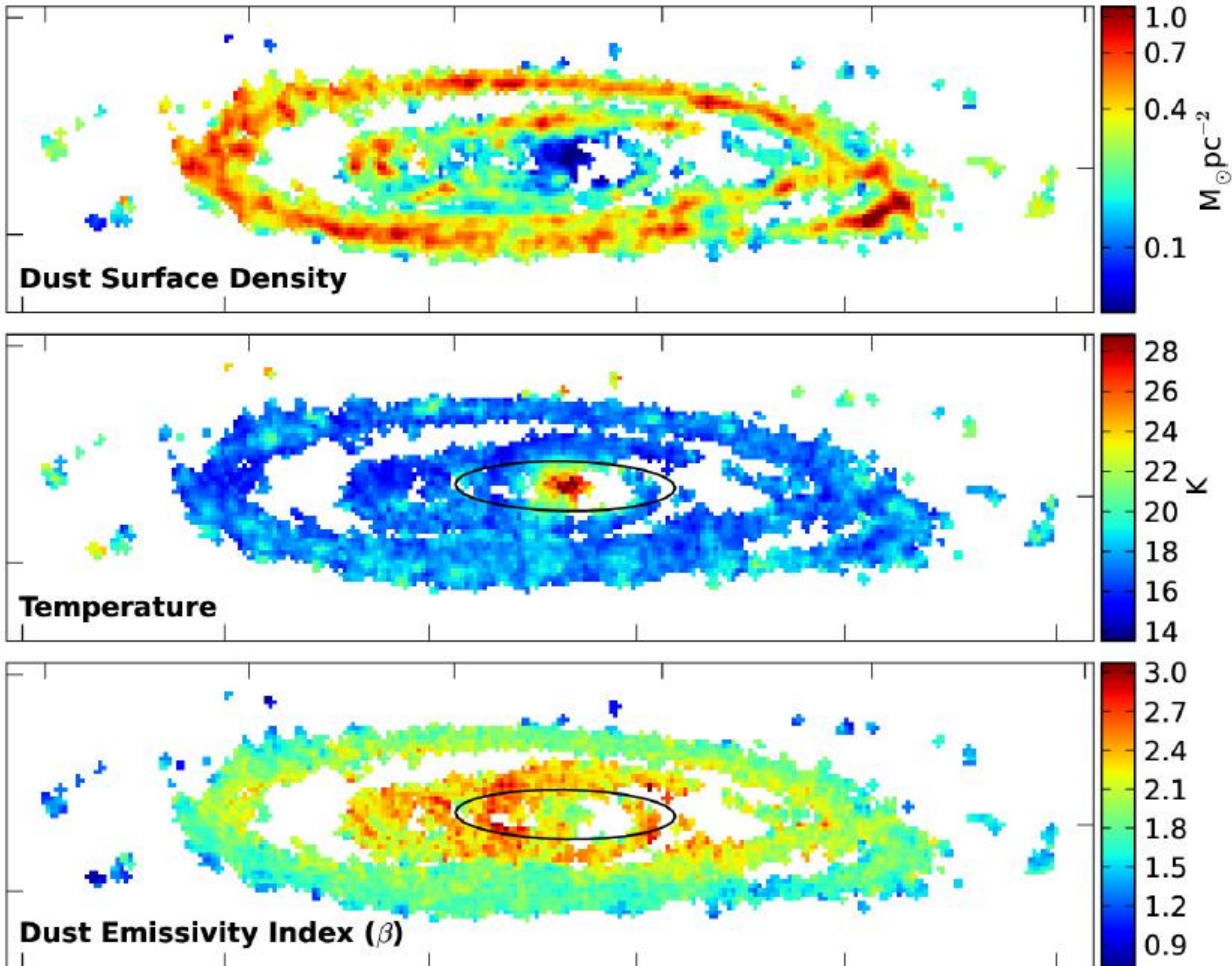
Herschel Exploitation of Local Galaxy Andromeda (HELGA)



- 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)

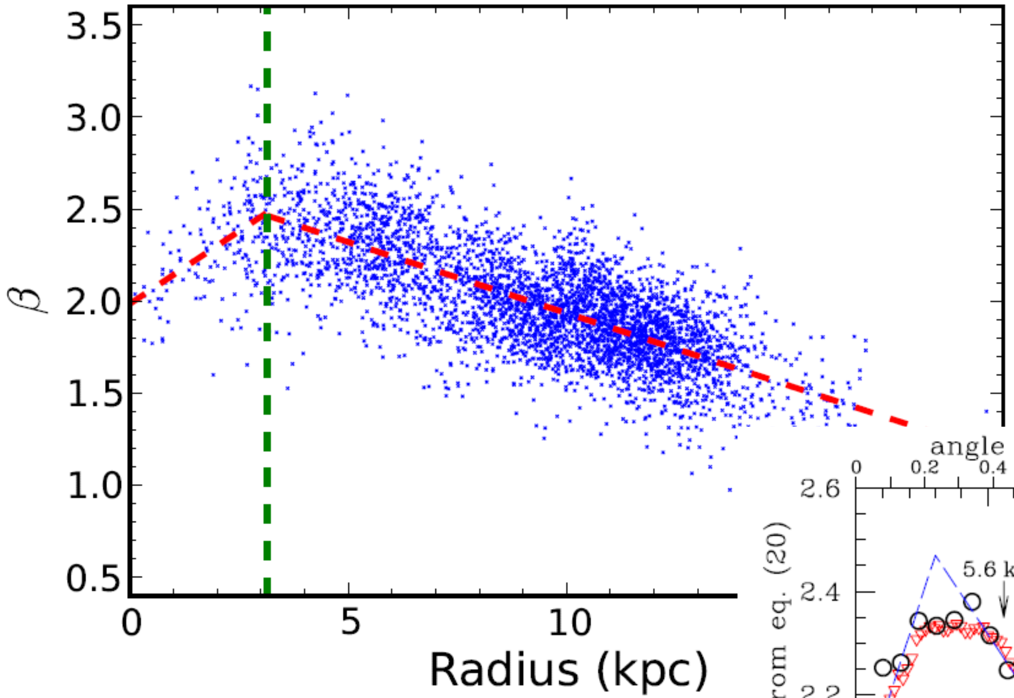
HELGA II: SED Fitting (Smith et al. 2012)

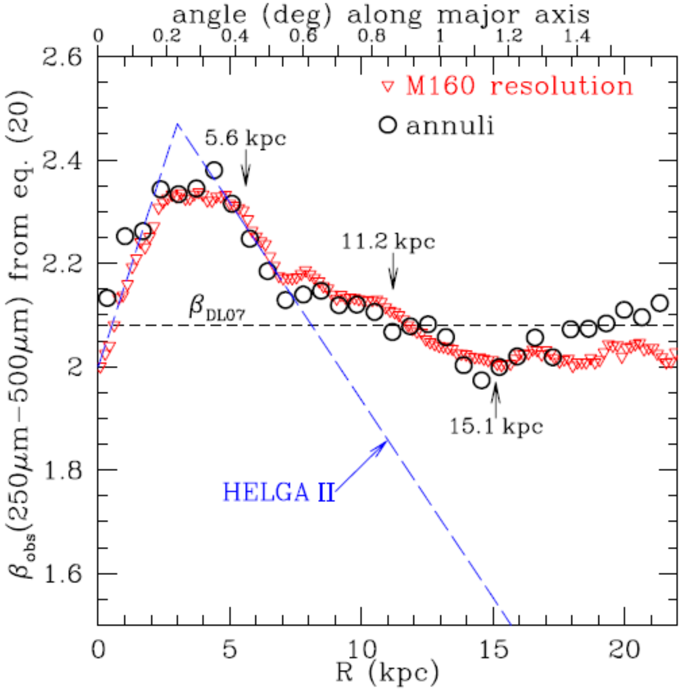
- Processing
  - Convolve and rebin all bands
  - 140pc resolution
  - Restrict to all 5 fluxes $> 5\sigma$
  - Take into account all correlated uncertainties
  - 4000 independent pixels
- Fit 1 modified blackbody model
- Find a need for a variable β
- No evidence for any cold-dust component
- Method is not optimal as information is thrown away



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)



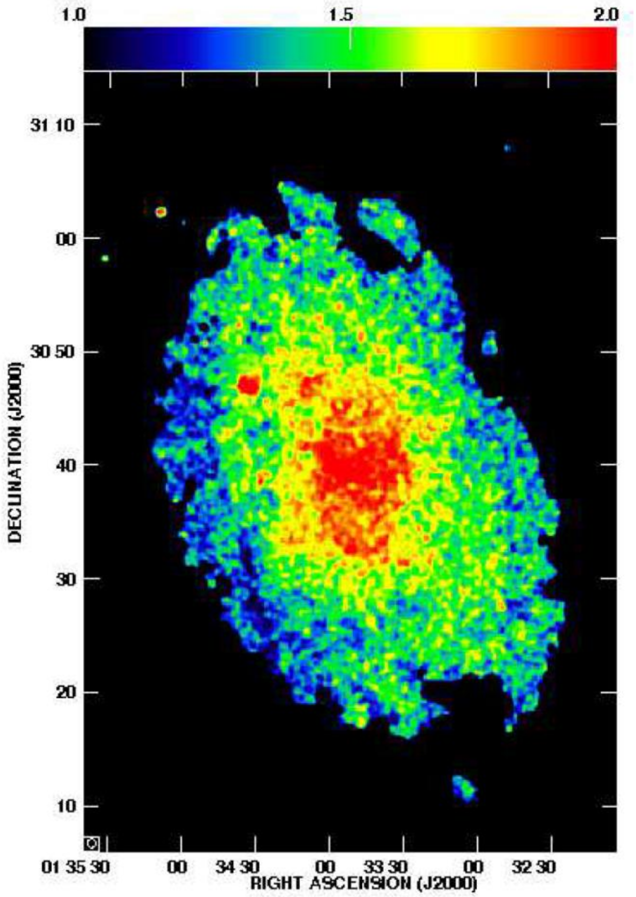


- Differences in β could be caused by changes in the grain size, icy mantles, or freshly formed grains.
- Problem is no obvious correlation with say properties of molecular gas to provide shielding etc…

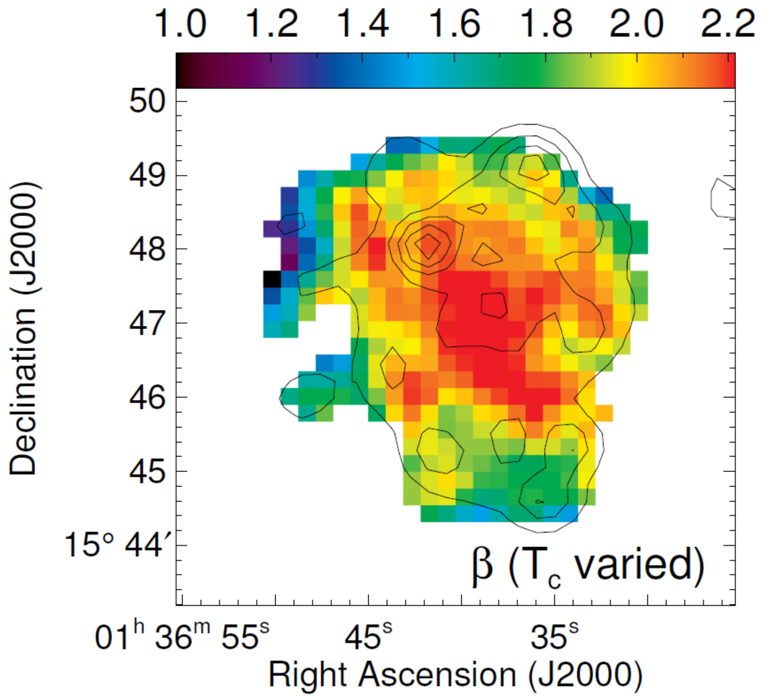
Variations of β in Other Galaxies

- Many studies have seen variations in other objects

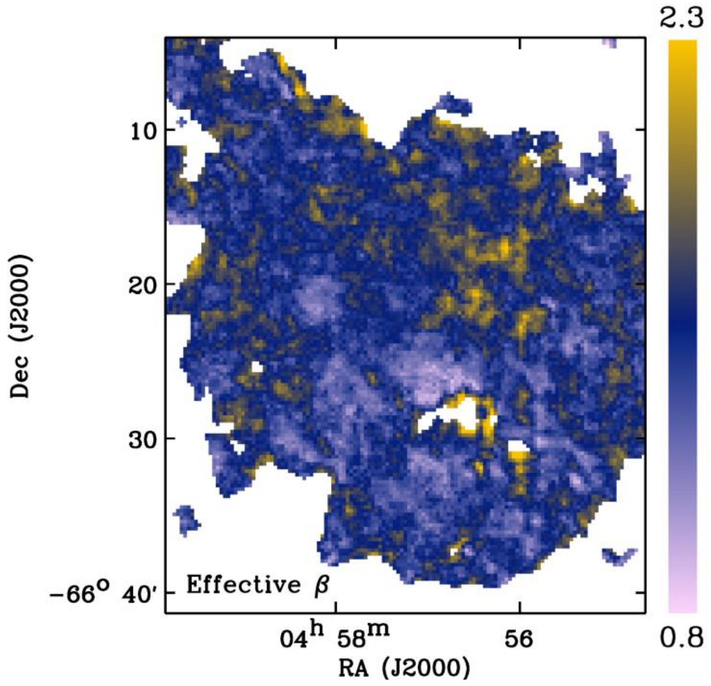
M33
Tabatabaei et al. 2013



KINGFISH 20 galaxies
(NGC0628)
Kirkpatrick et al. 2014

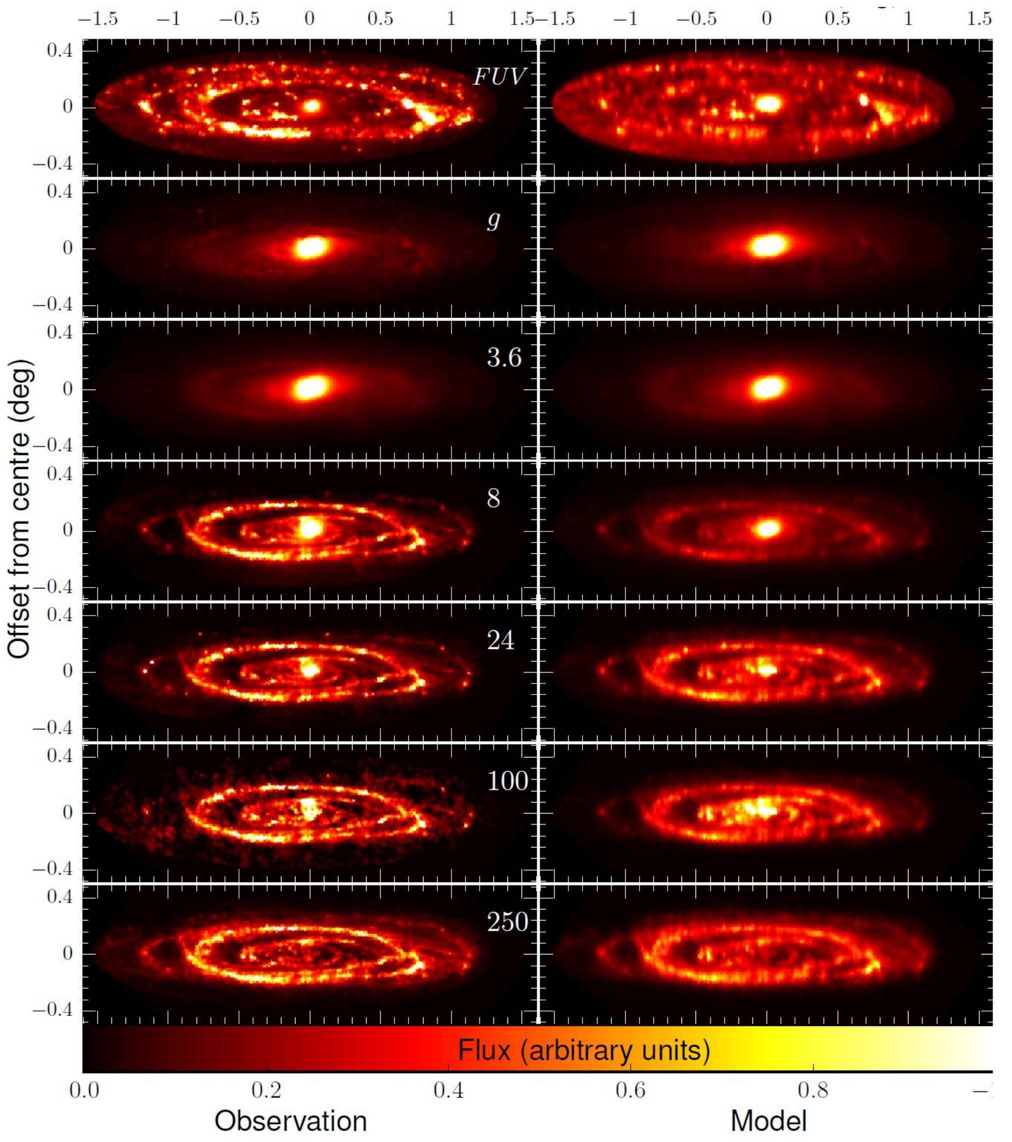


LMC Complex N11
Galametz et al. 2015

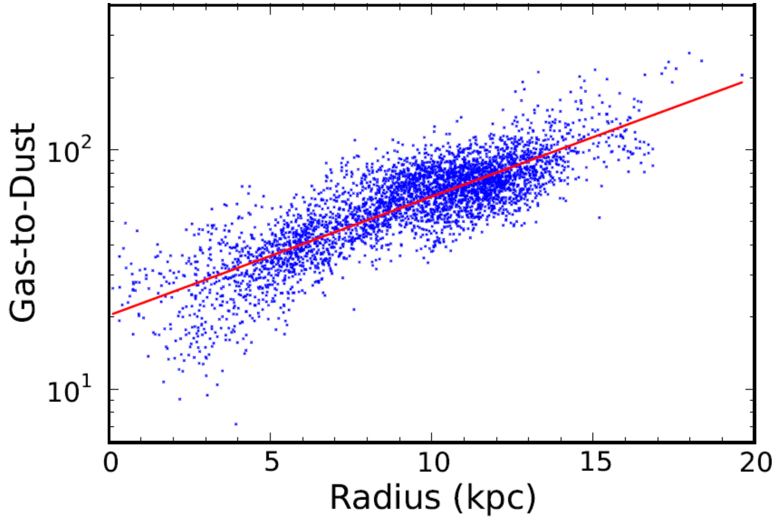


Dust Heating Results

- Both HELGA II (Smith et al. 2012) and Groves et al. (2012) found dust in the centre is heated by the stars in the bulge
- Dust temperature varies roughly as you expect with the radiation field in the bulge.
- HELGA VII (Viaene et al. 2016), performed a full radiative transfer analysis
  - Dust is mainly heated (91% of the absorbed luminosity) by the evolved stellar population
  - The bulge heating extends out into the main 10 kpc ring
  - Attenuation curve is consistent with other previous estimates



Radial Dust and Metals Distribution

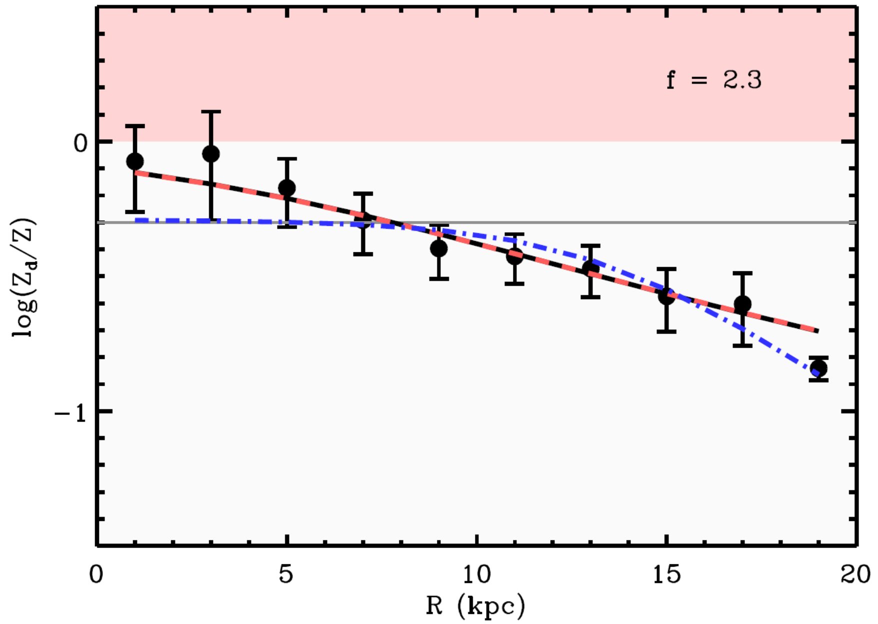


- In HELGA II, we found that literature metallicity gradients were in agreement with the gas-to-dust ratio assuming a constant fraction of dust is locked into dust grain.

- Lars Mattsson (HELGA V, 2014) used new published metallicity measurements

- Found the dust-to-gas gradient is steeper than the metallicity gradient. In his model this is suggestive of grain-growth in the ISM.

- However, there are degeneracies between dust production and destruction sources in this model



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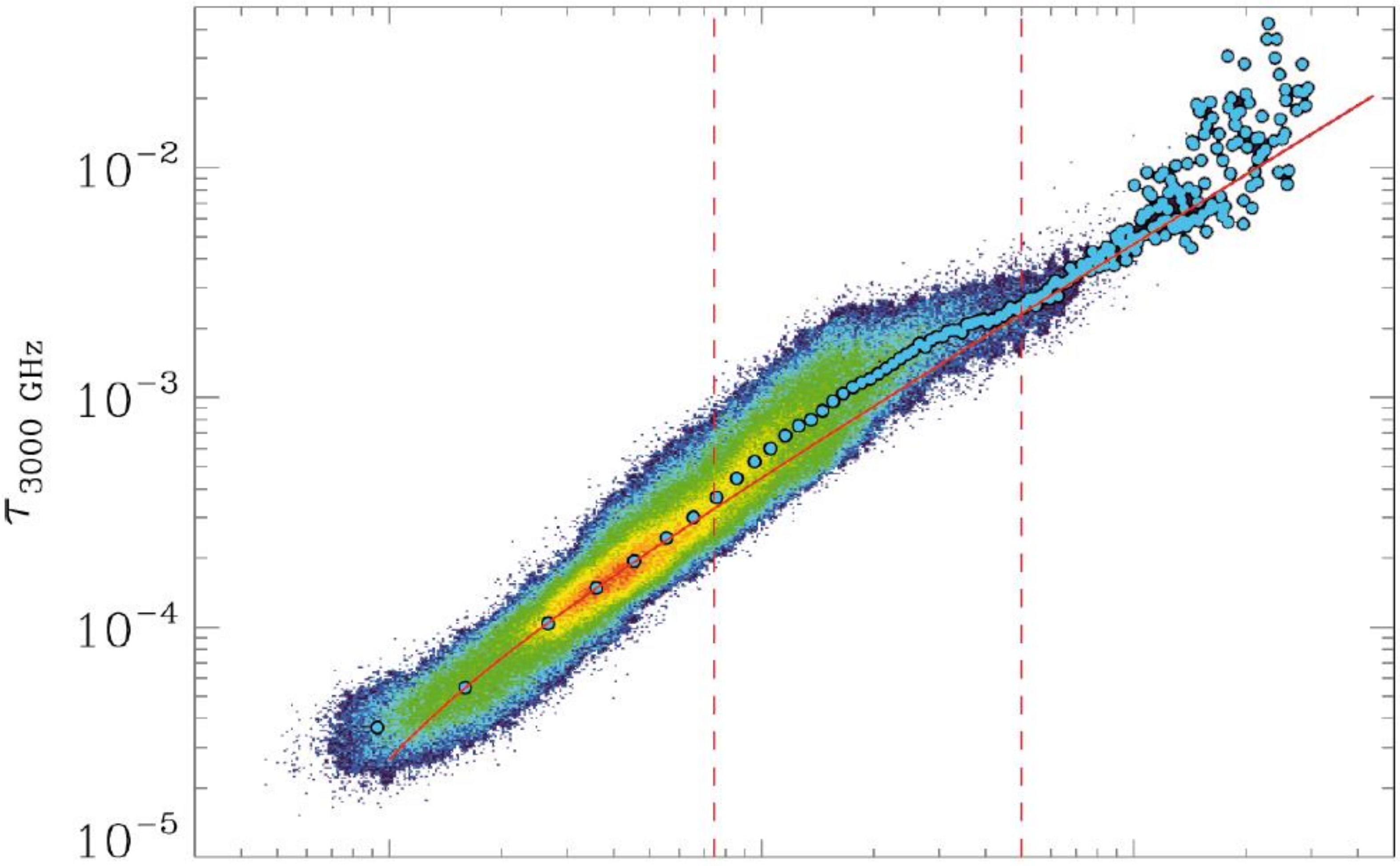
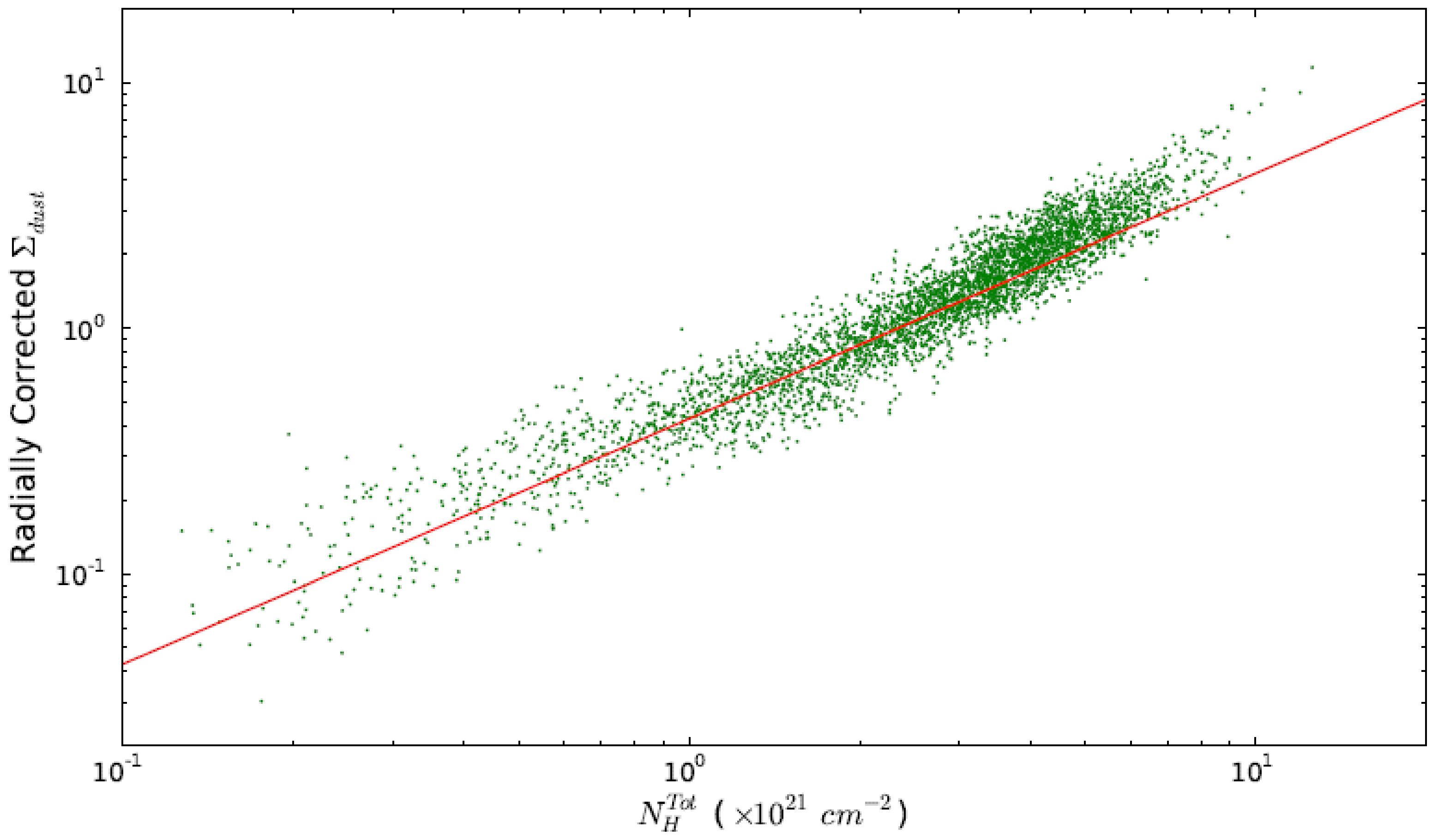
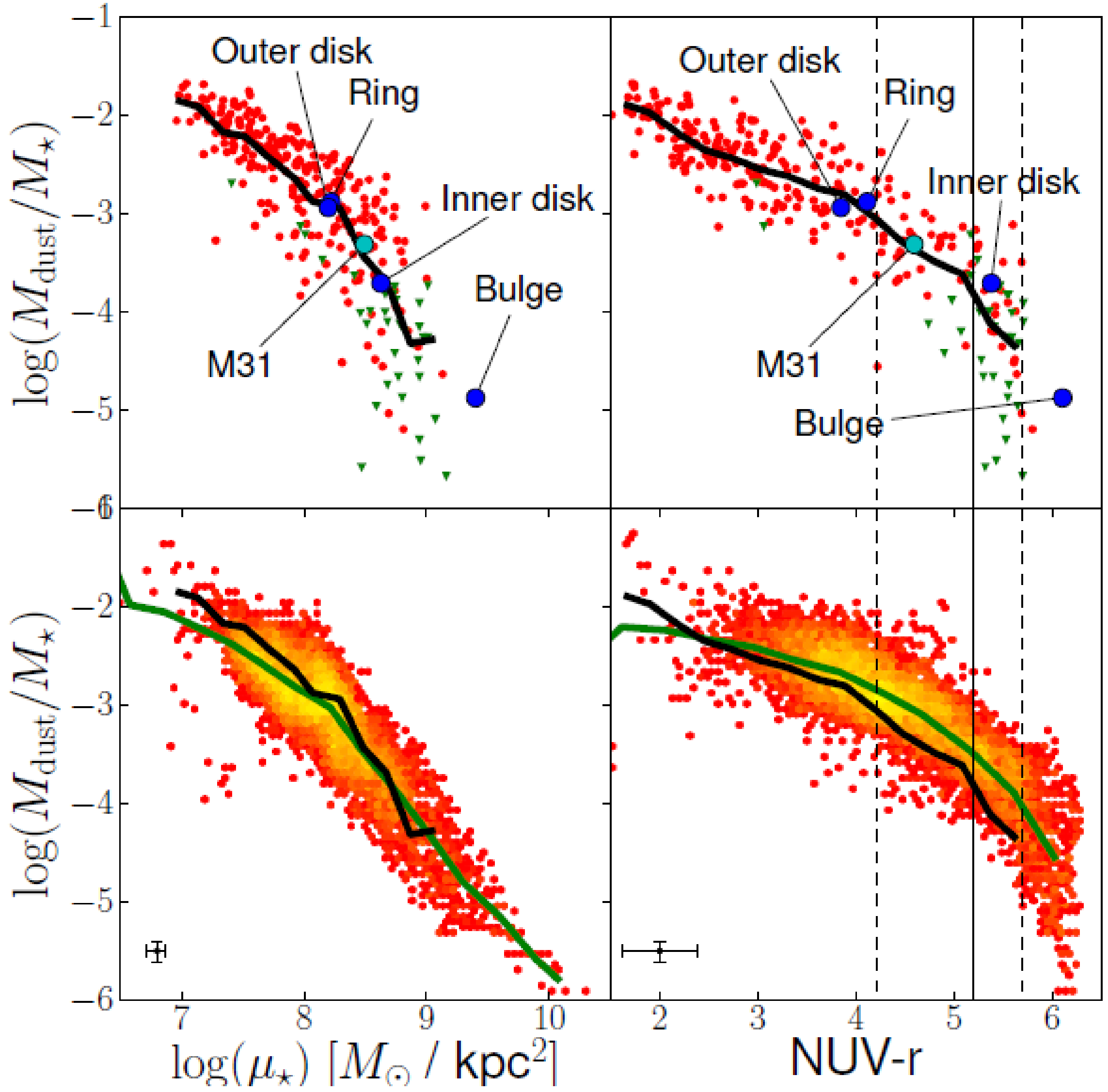


Is there Dark Gas in Andromeda?

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



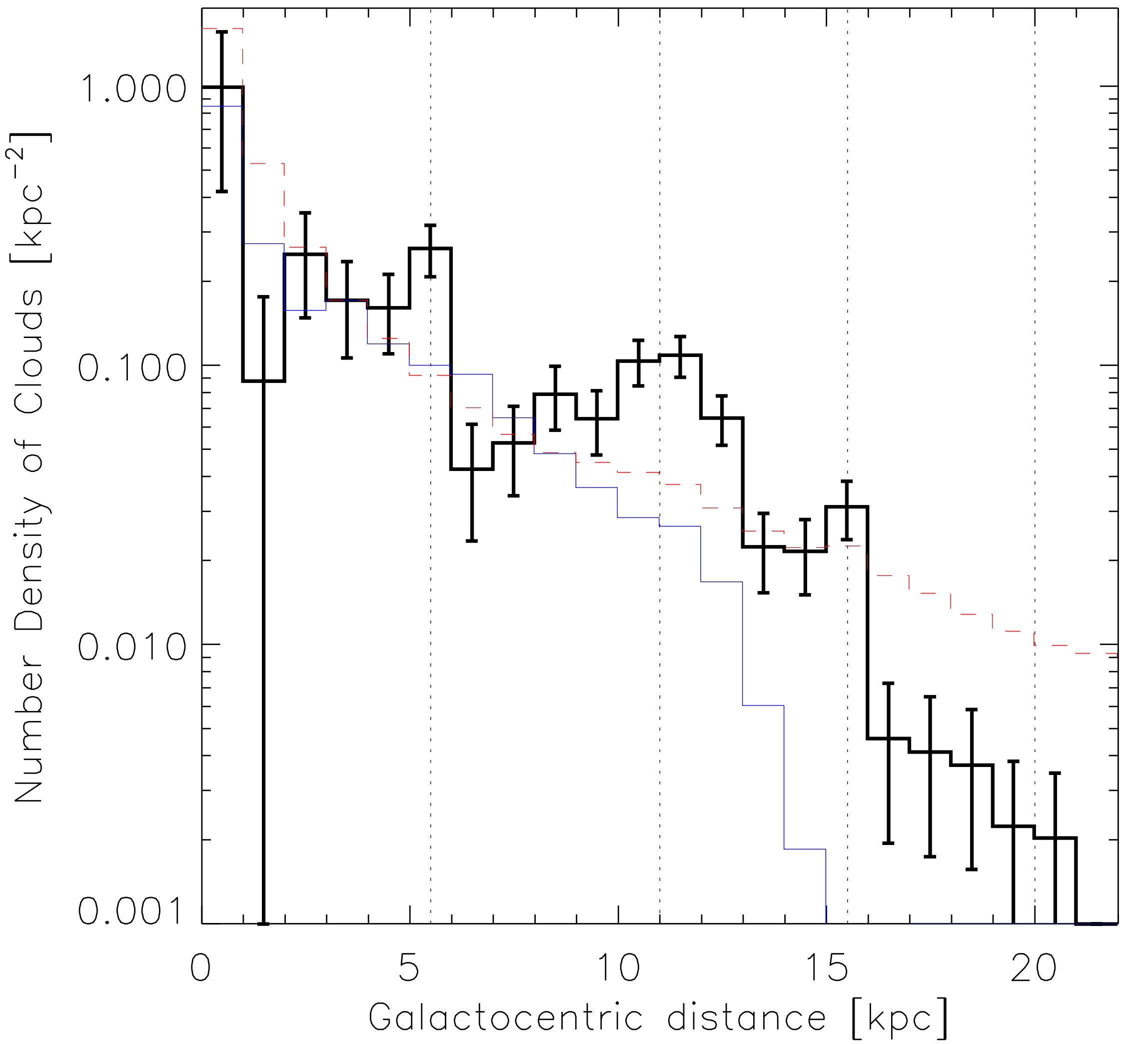
HELGA IV: Viaene et al. (2014)



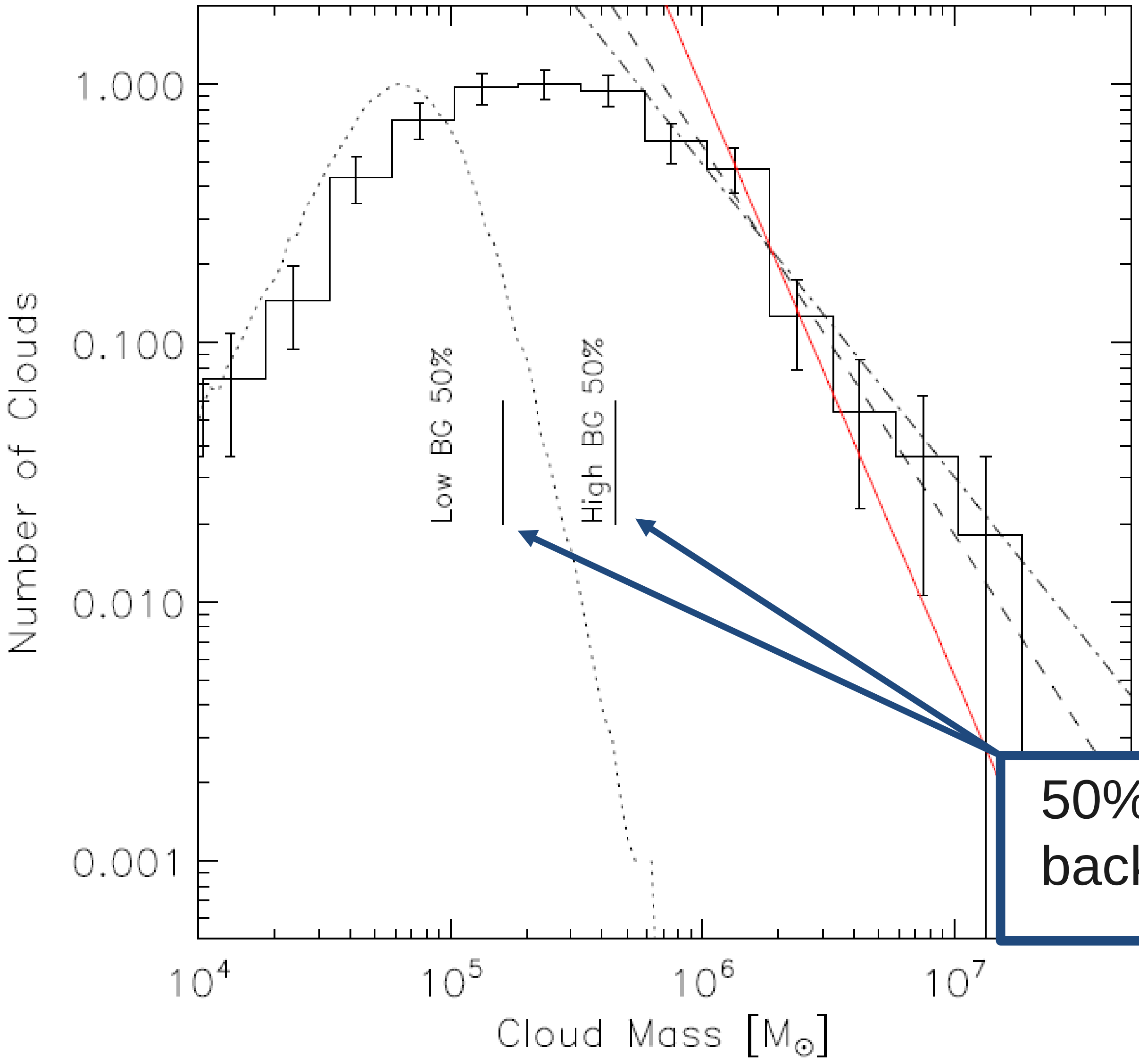
- MAGPHYS panchromatic fits to entire image
- Individual regions fit on global dust scaling relations (Cortese et al.)

HELGA VI – Kirk et al.

- Run CSAR source extraction to find GMCs or associations of GMCs ⟶ call both clouds
- Most are GMC complexes
- Find 326 clouds (5σ)
- Only 5.8% are within 100pc of IR dark clouds
- Masses $10^4 - 10^7\ M_\odot$, median $4.1 \times 10^5\ M_\odot$



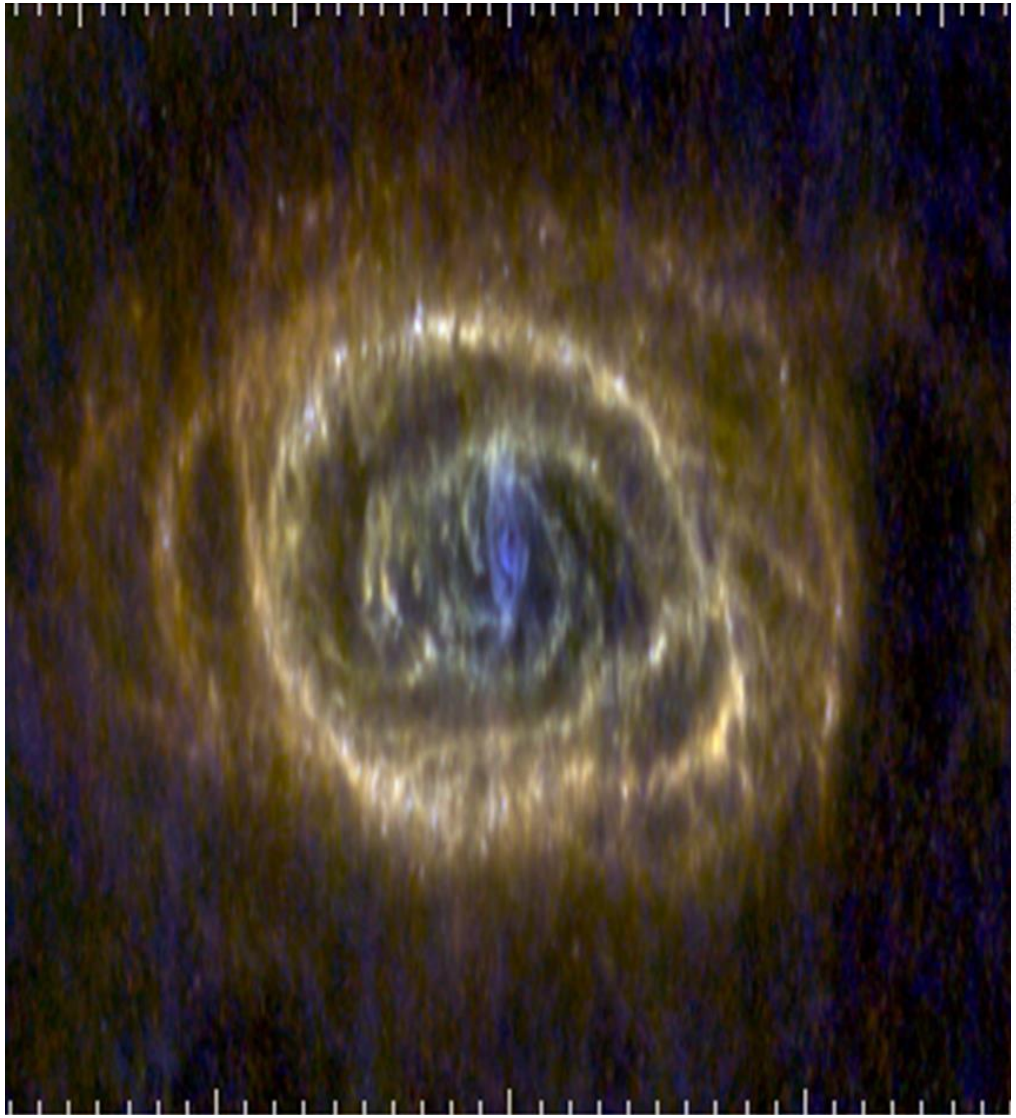
HELGA VI - continued

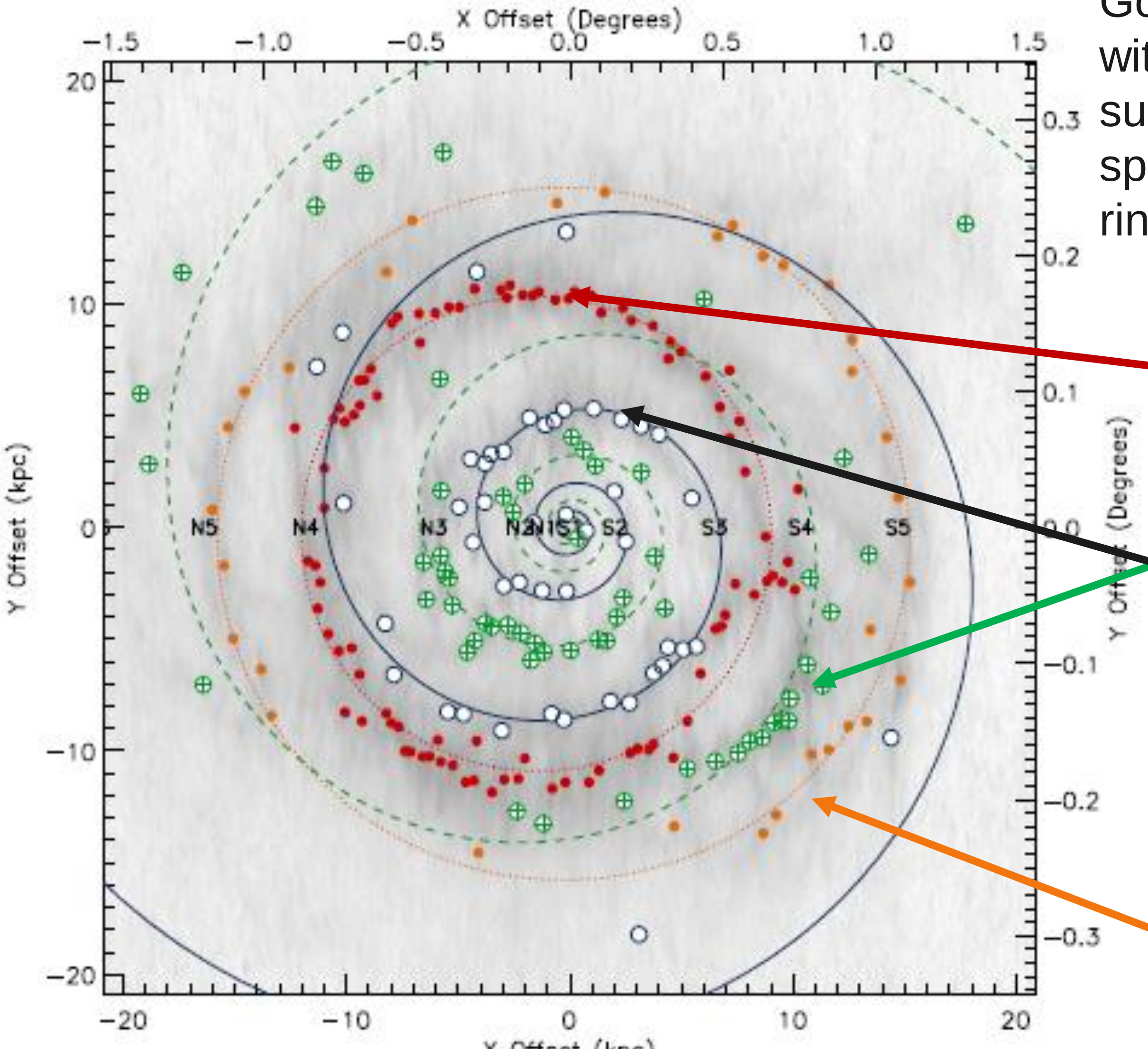


50% Completeness (low/high background)

Cloud mass distribution is consistent with the Milky Way (dashed line)

De-projected 250μm





Gordon et al. with Spitzer suggested 2 spiral arm and 1 ring

10 kpc Ring (offset from centre)

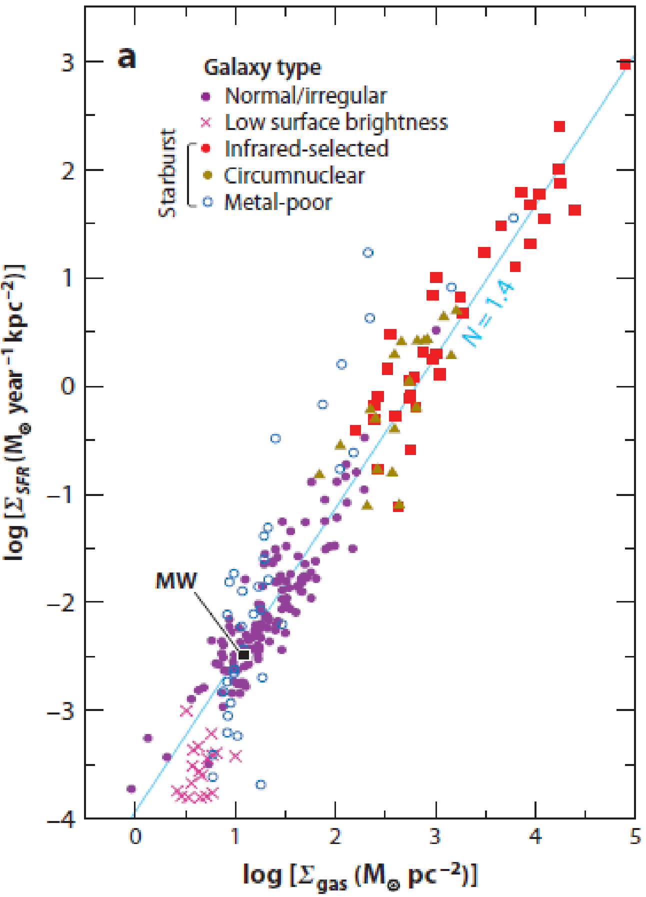
Spiral Arms

15 kpc Ring

Star-Formation Law in Galaxies

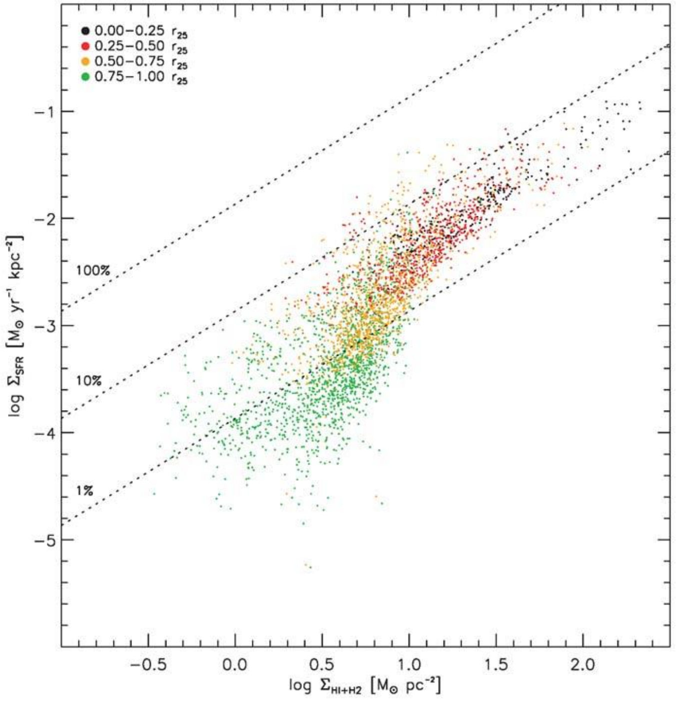
- Ultimate goal, to understand the key physical drivers and regulators of star-formation, and their defining physical relationships
- Andromeda (& soon M33) are unique as can get detailed SFH and current SFR as resolve individual stars with Hubble
- Breaks down in ULIRGS, and low metallicities

Global Scale



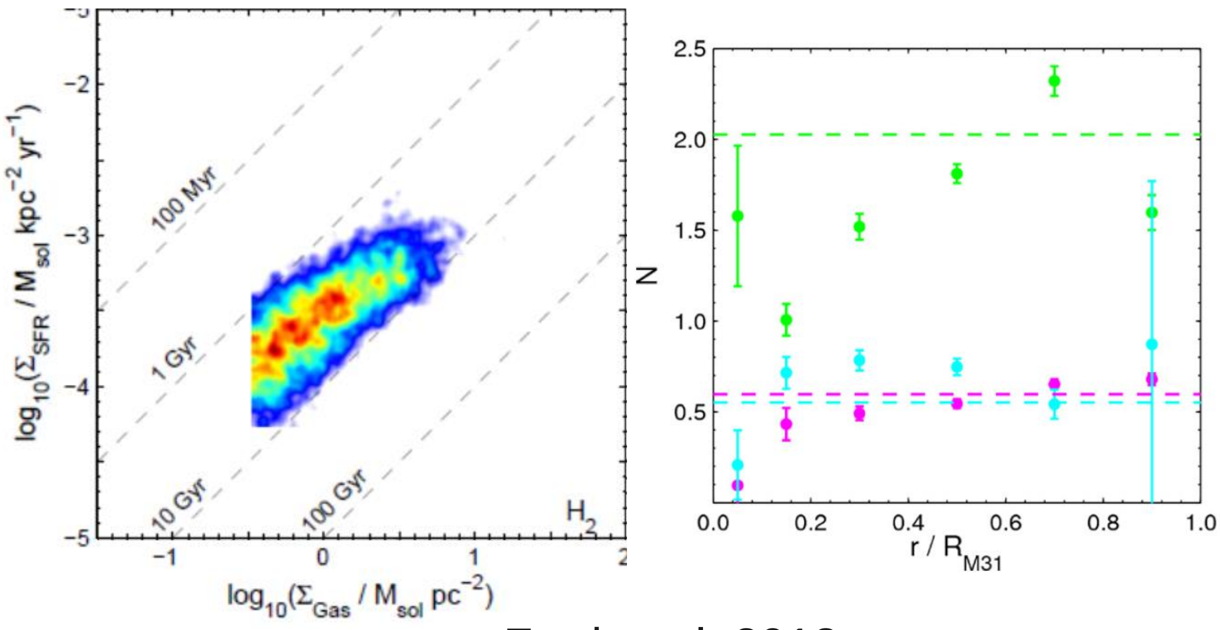
Kennicutt (multiple refs)

Nearby Galaxies



Bigiel et al. 2008 (THINGS)

Andromeda – HELGA III



Ford et al. 2013

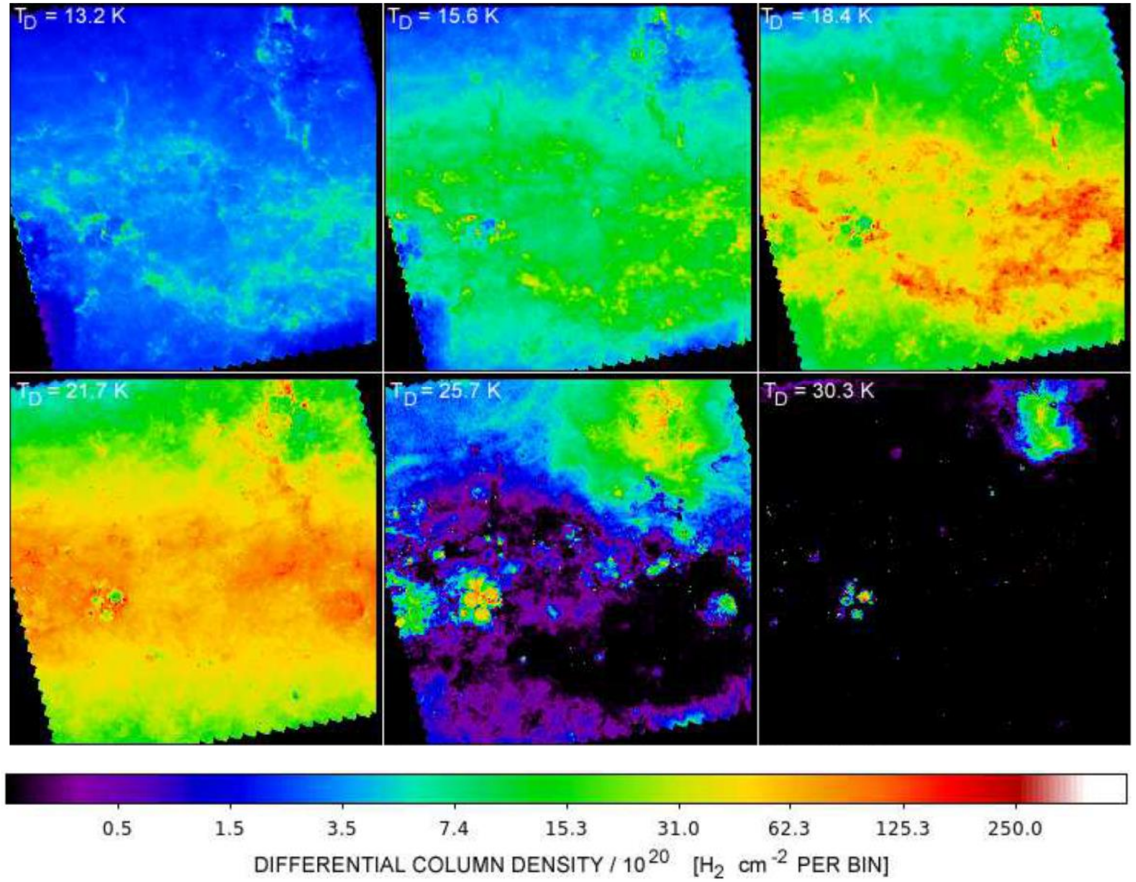
How can we make more progress?

- 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)

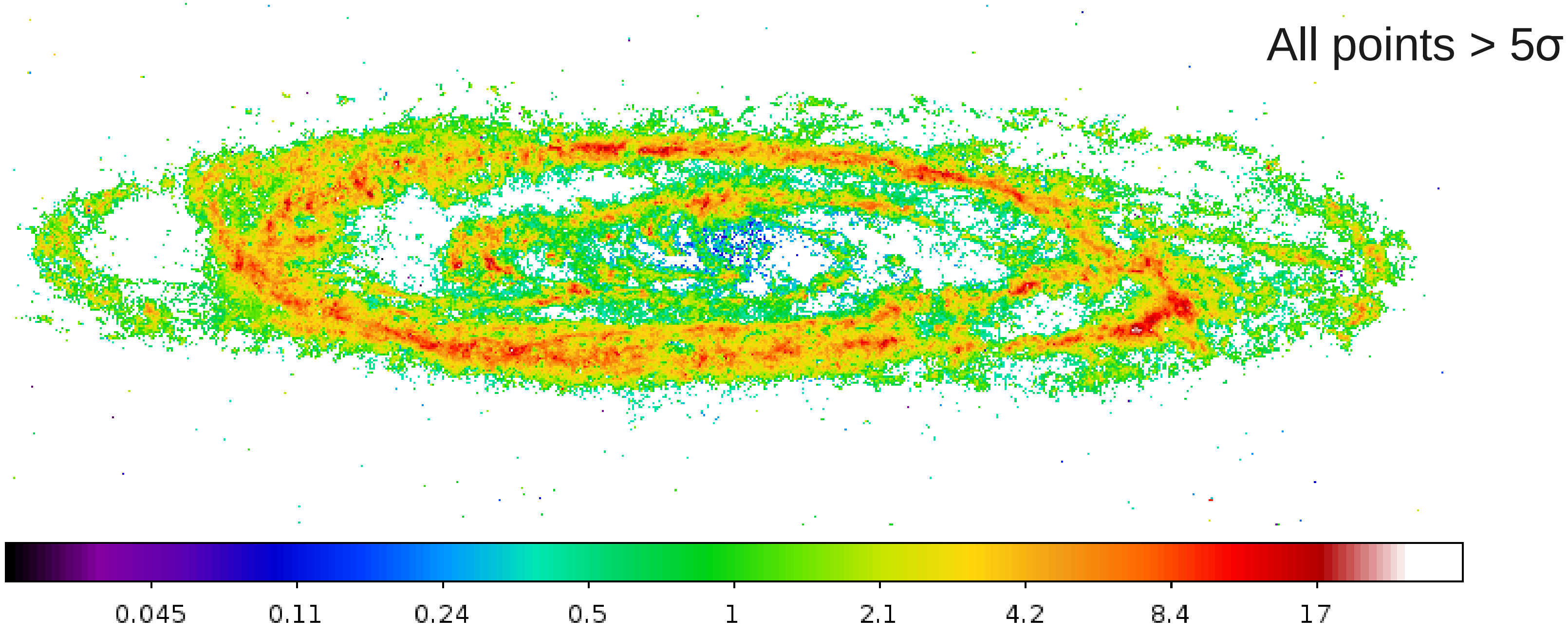


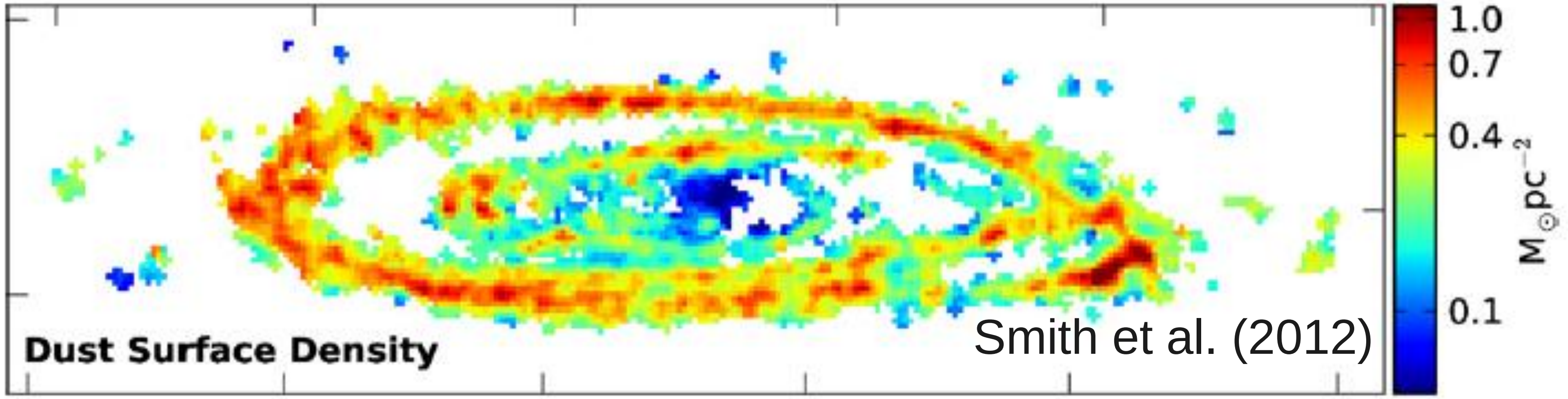
(slightly abbreviated image)

- 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. in prep, Marsh et al. submitted





Smith et al. (2012)

PPMAP temperatures

- T = 10.0 K
- T = 11.6 K
- T = 13.4 K
- T = 15.5 K
- T = 18.0 K
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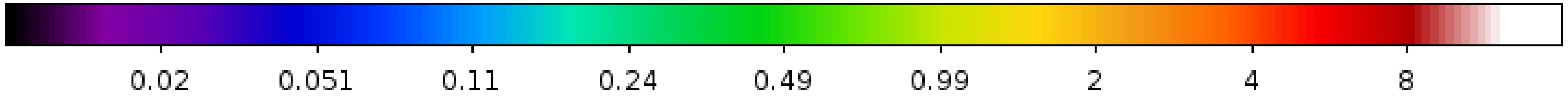

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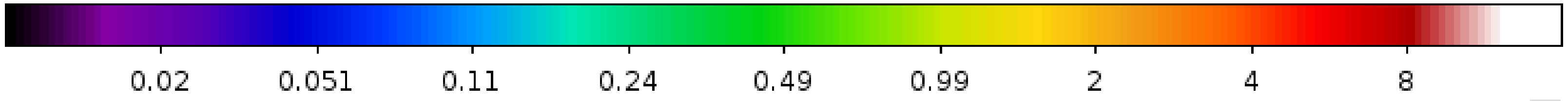

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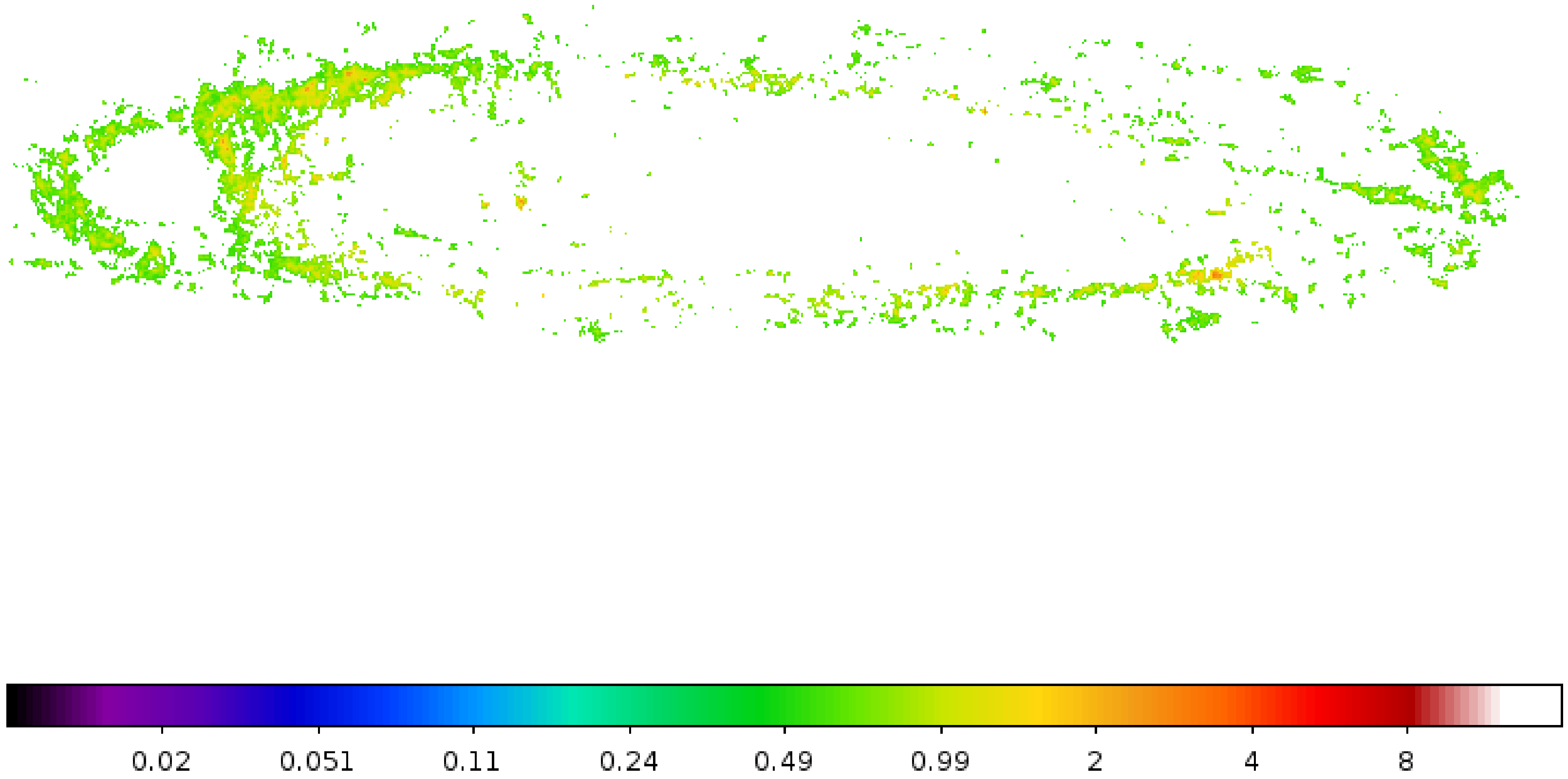

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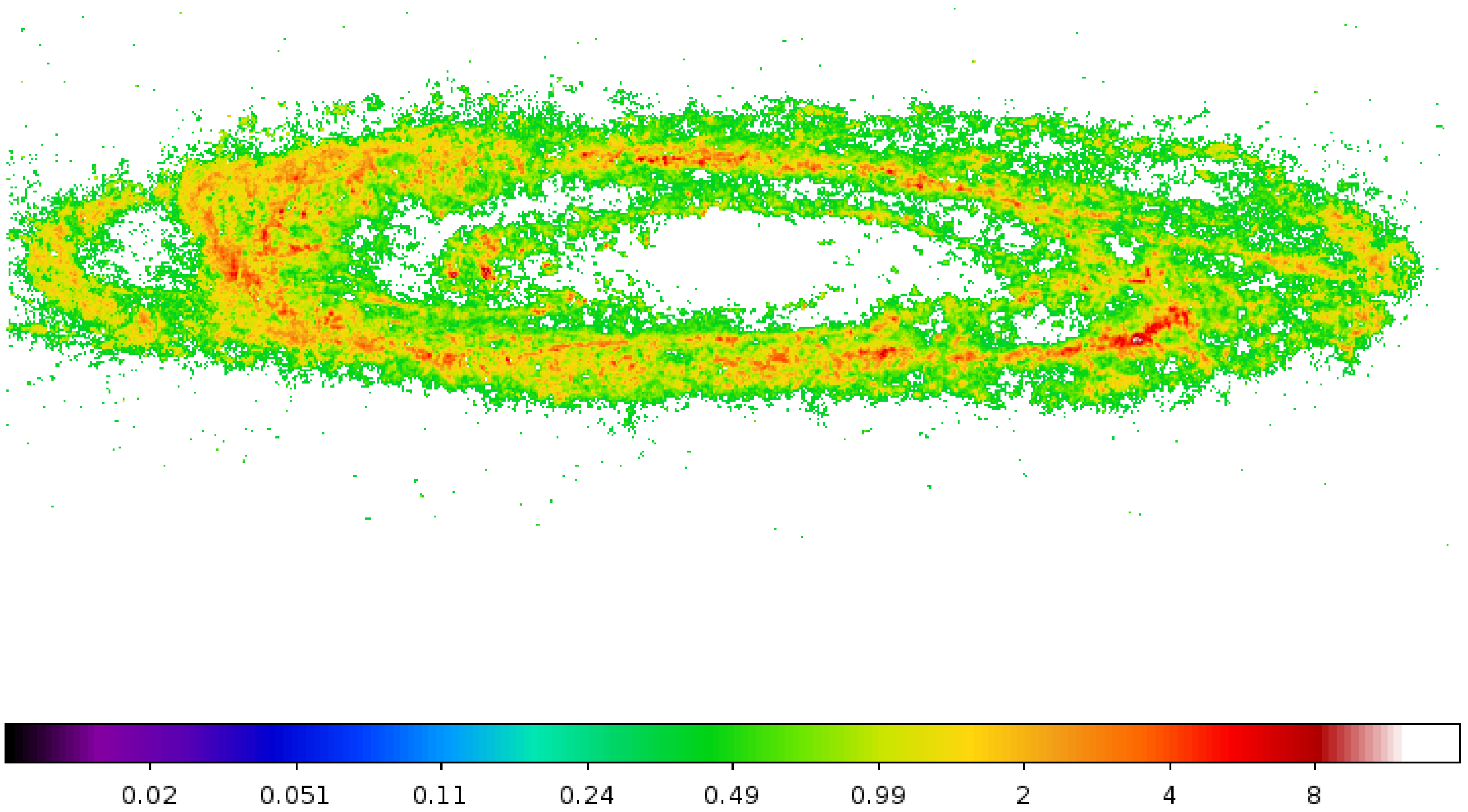

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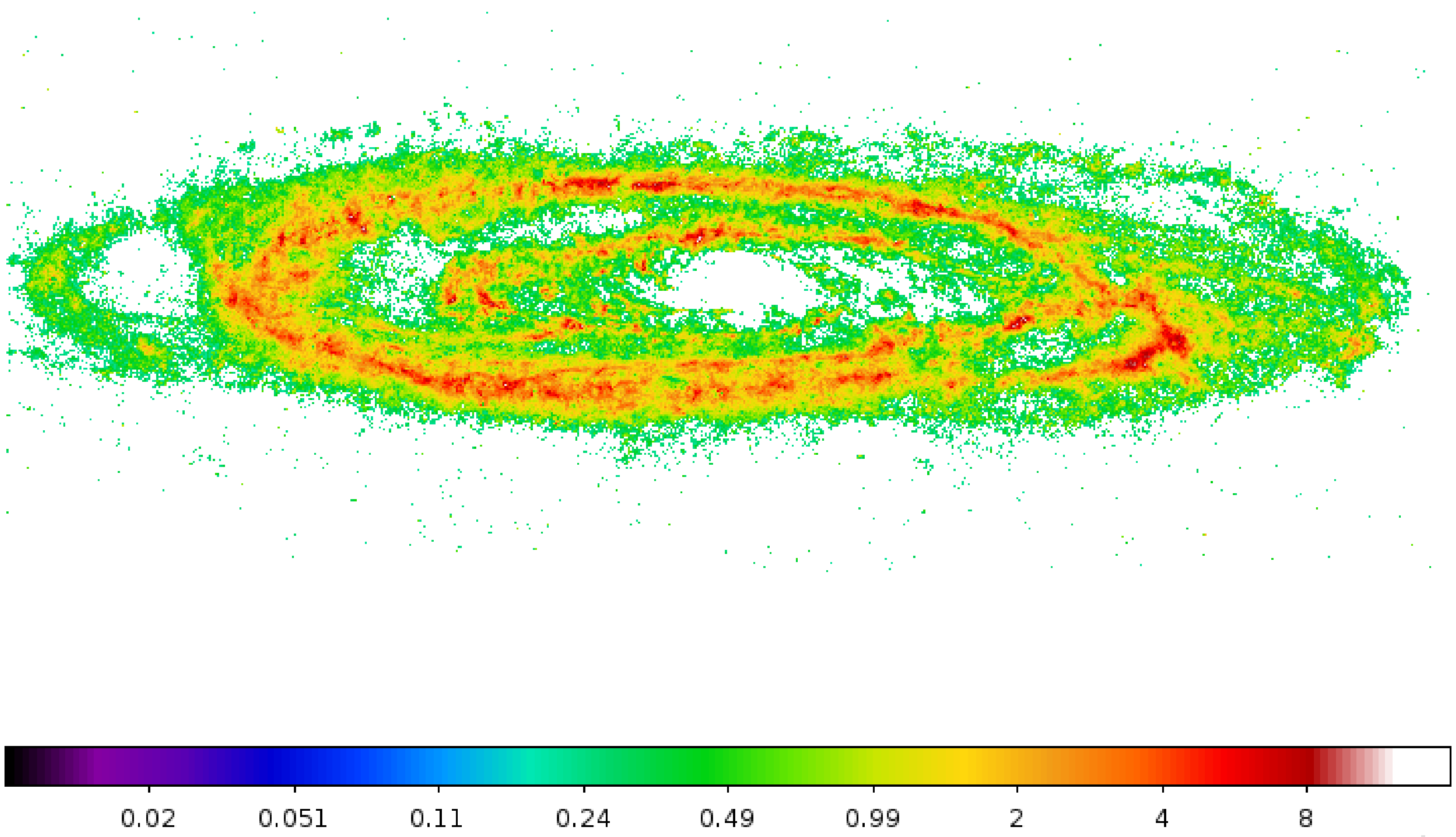

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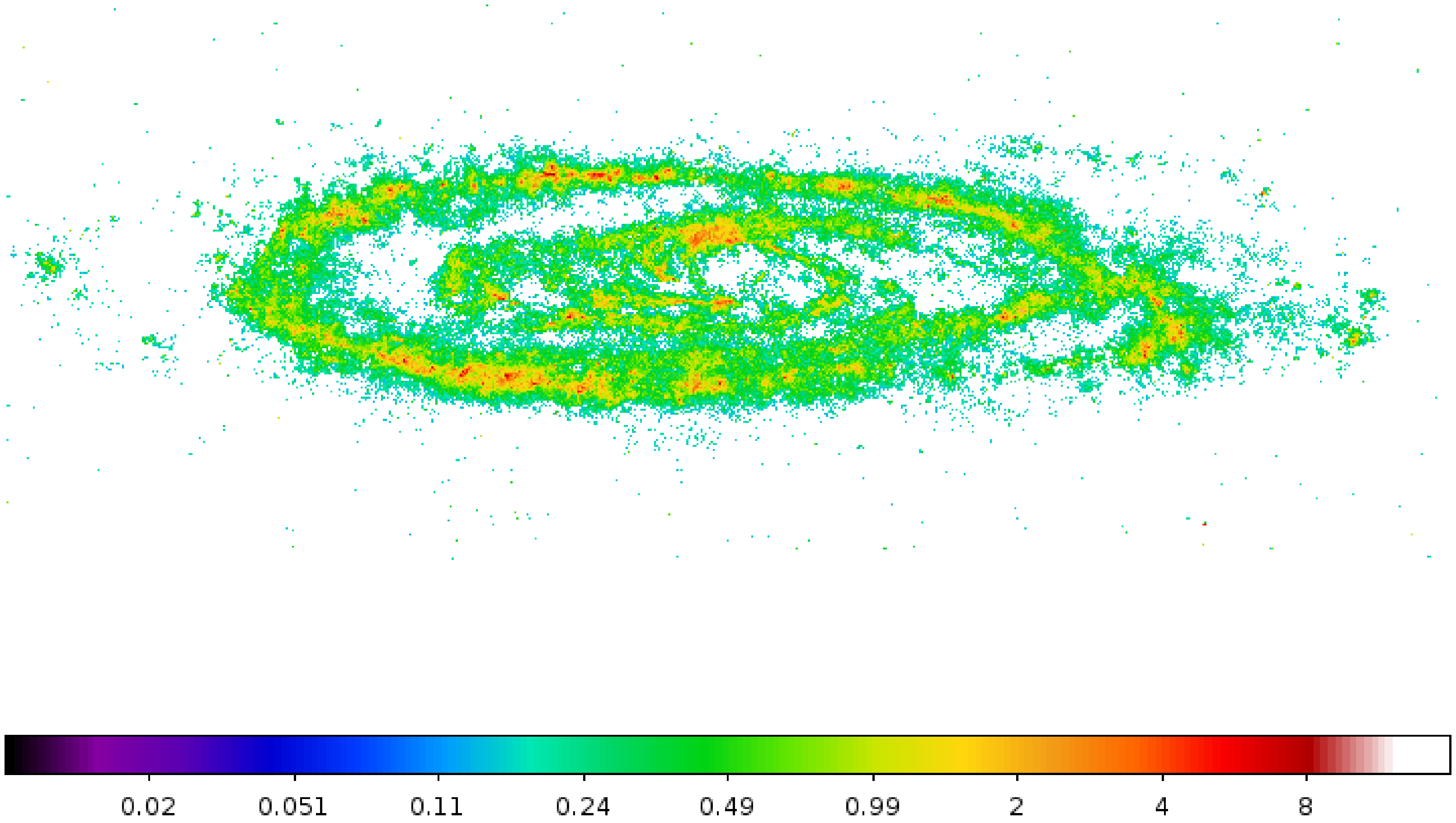

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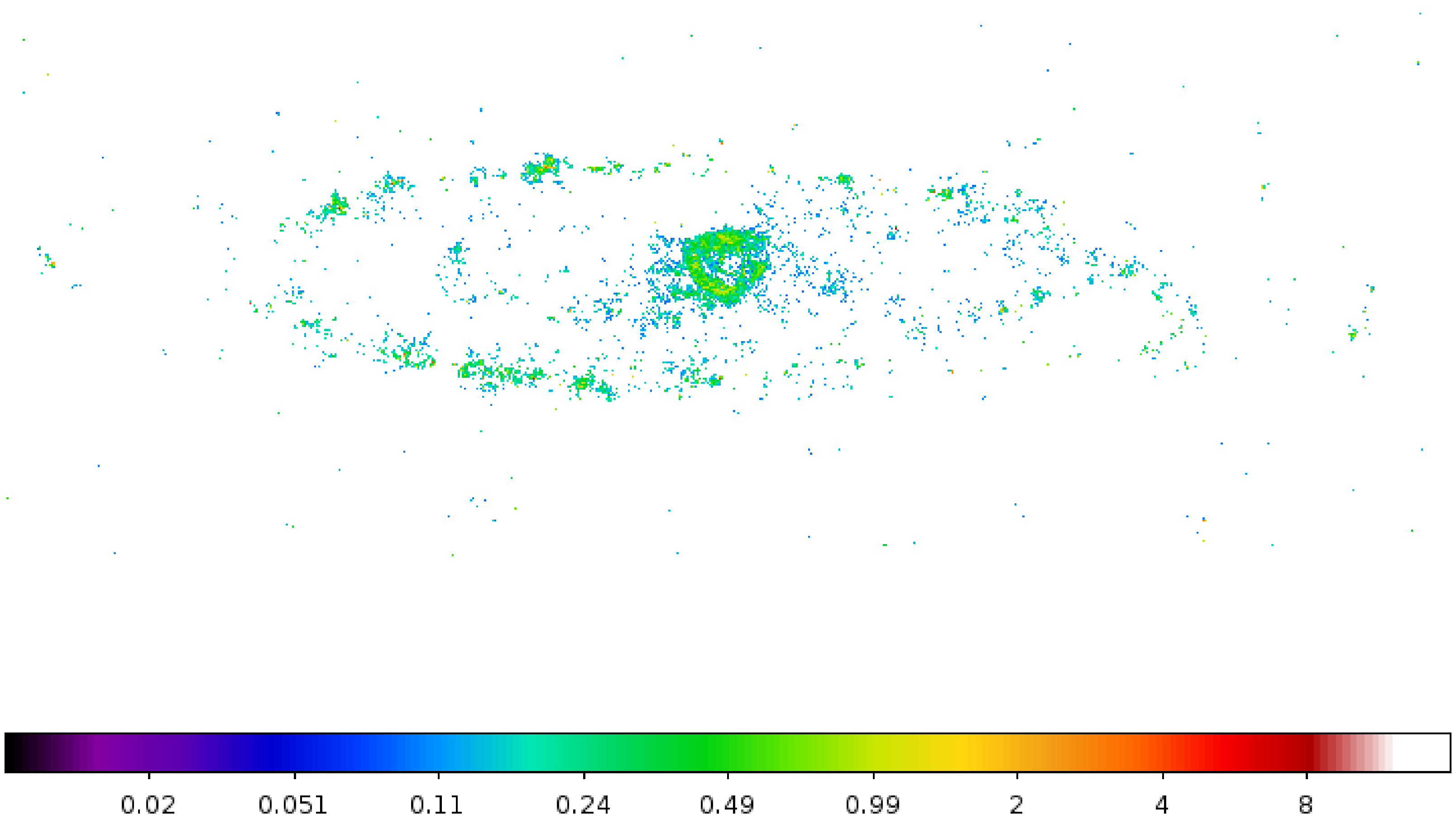

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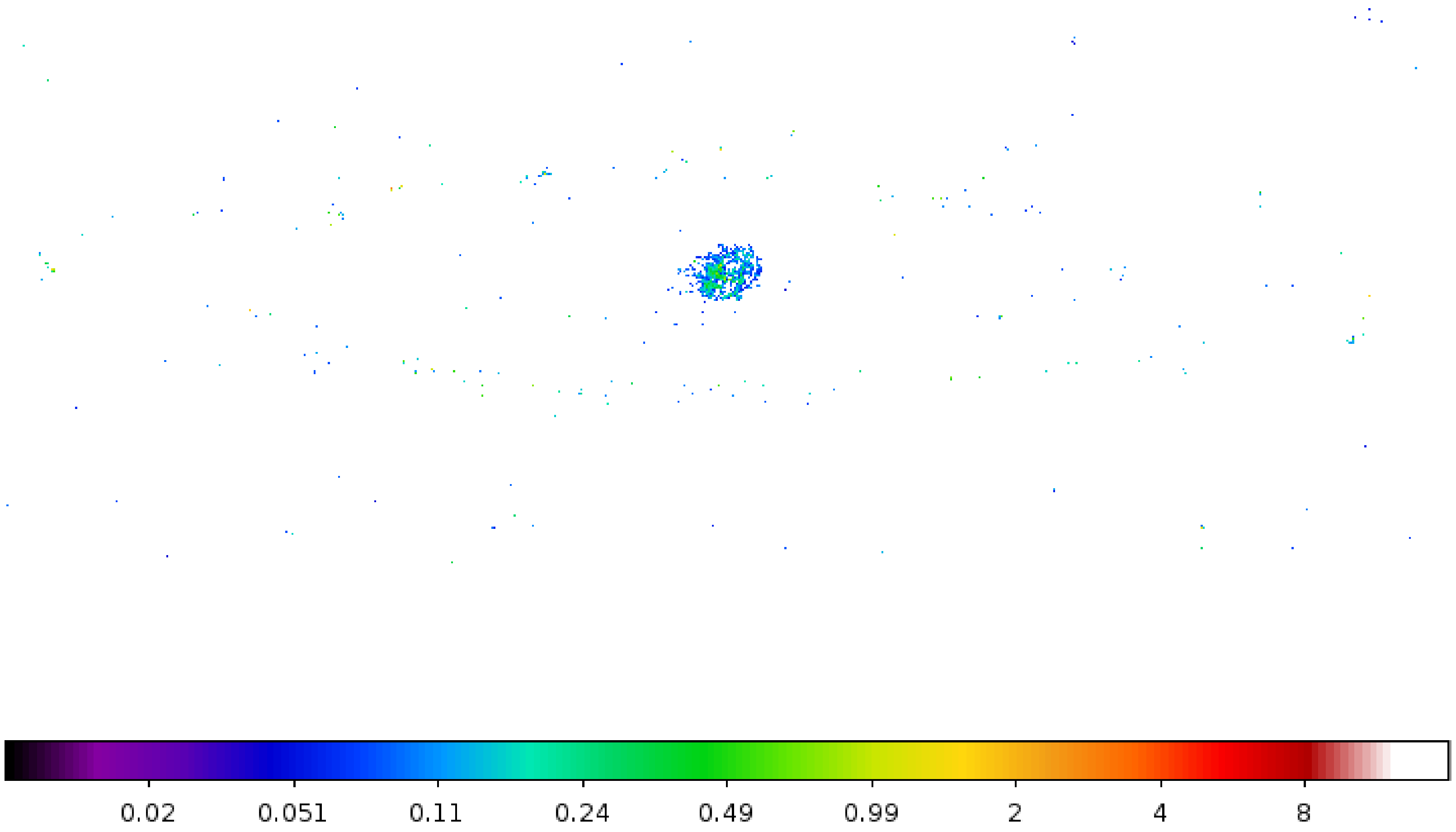

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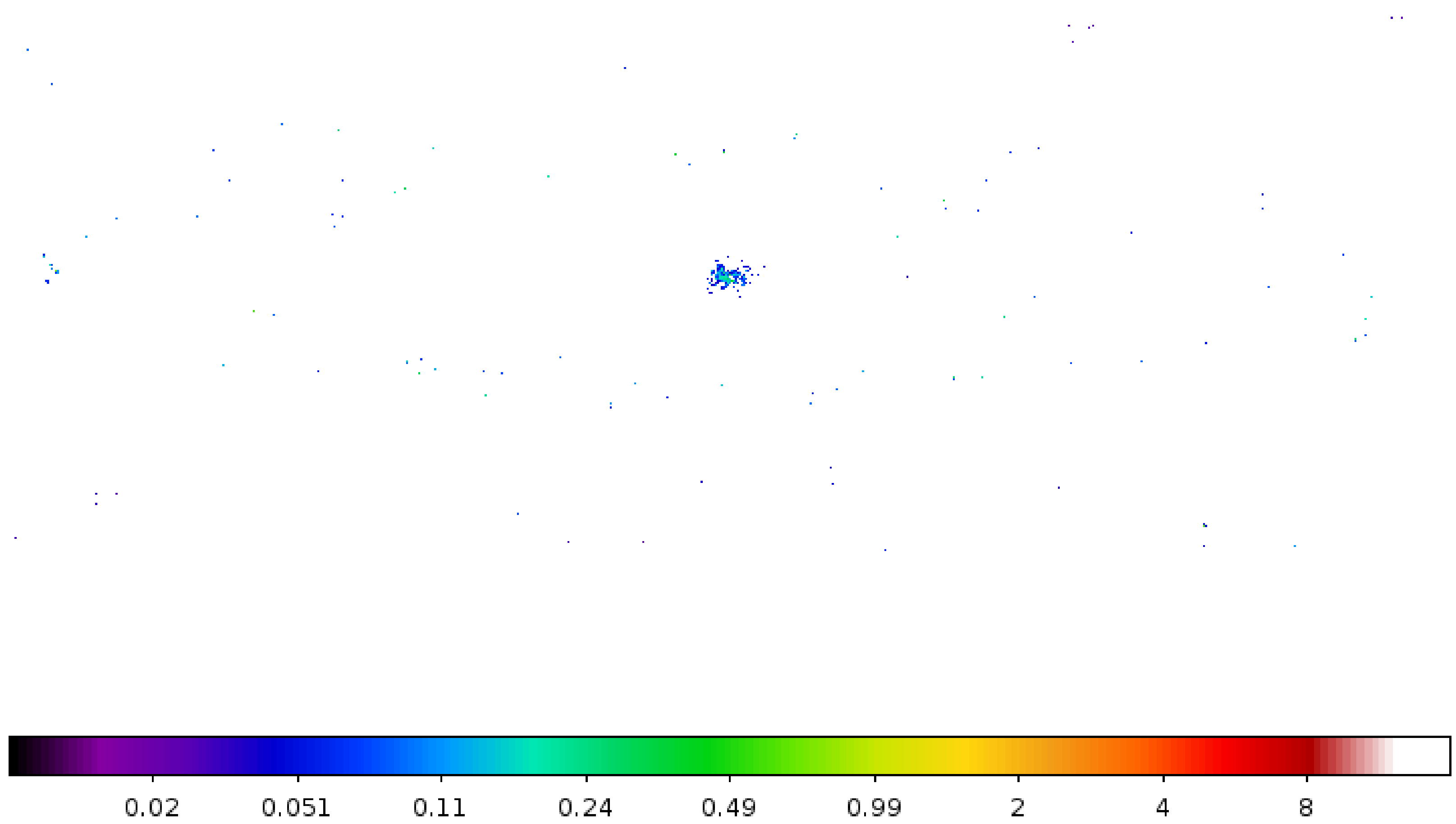

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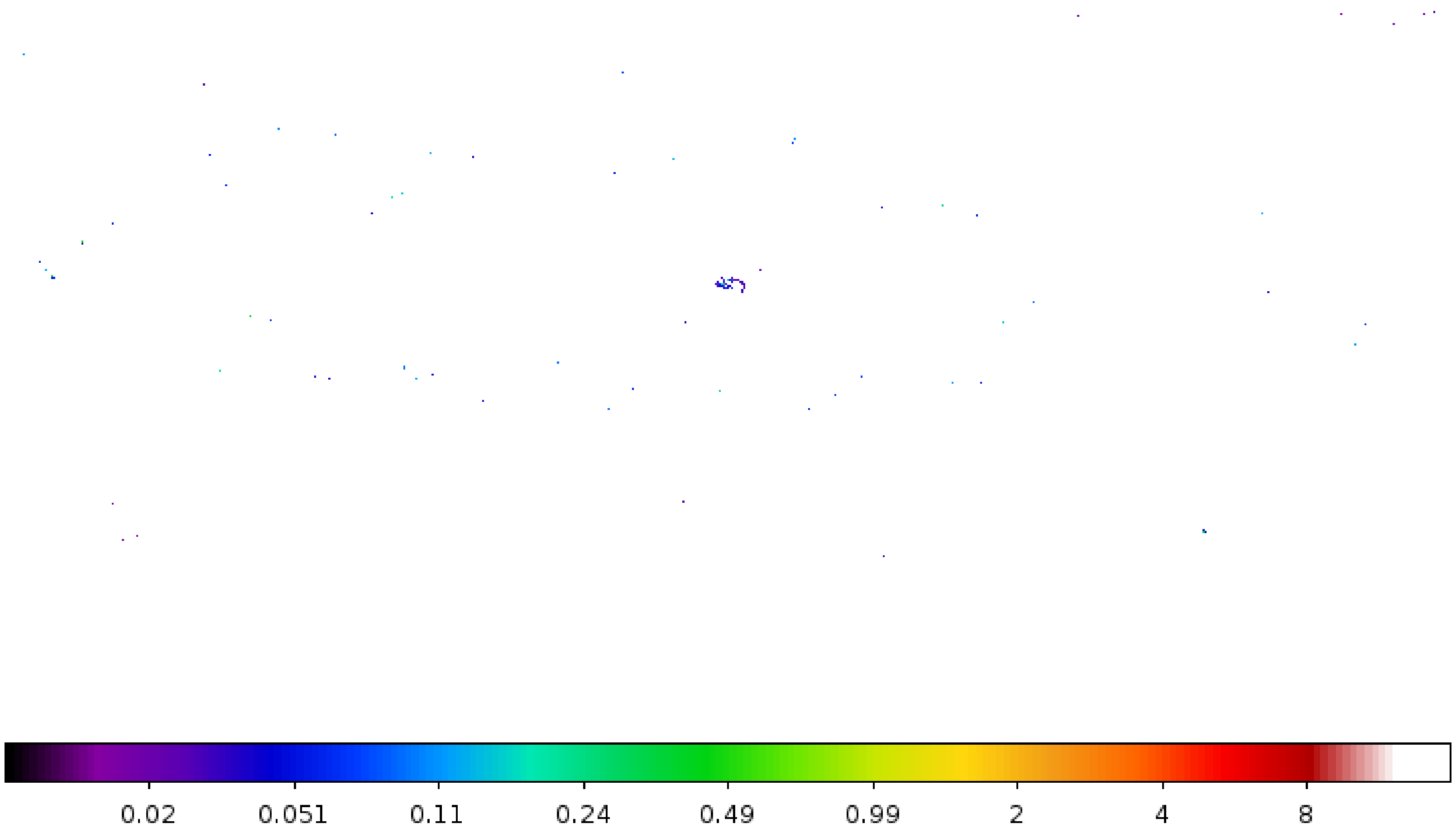

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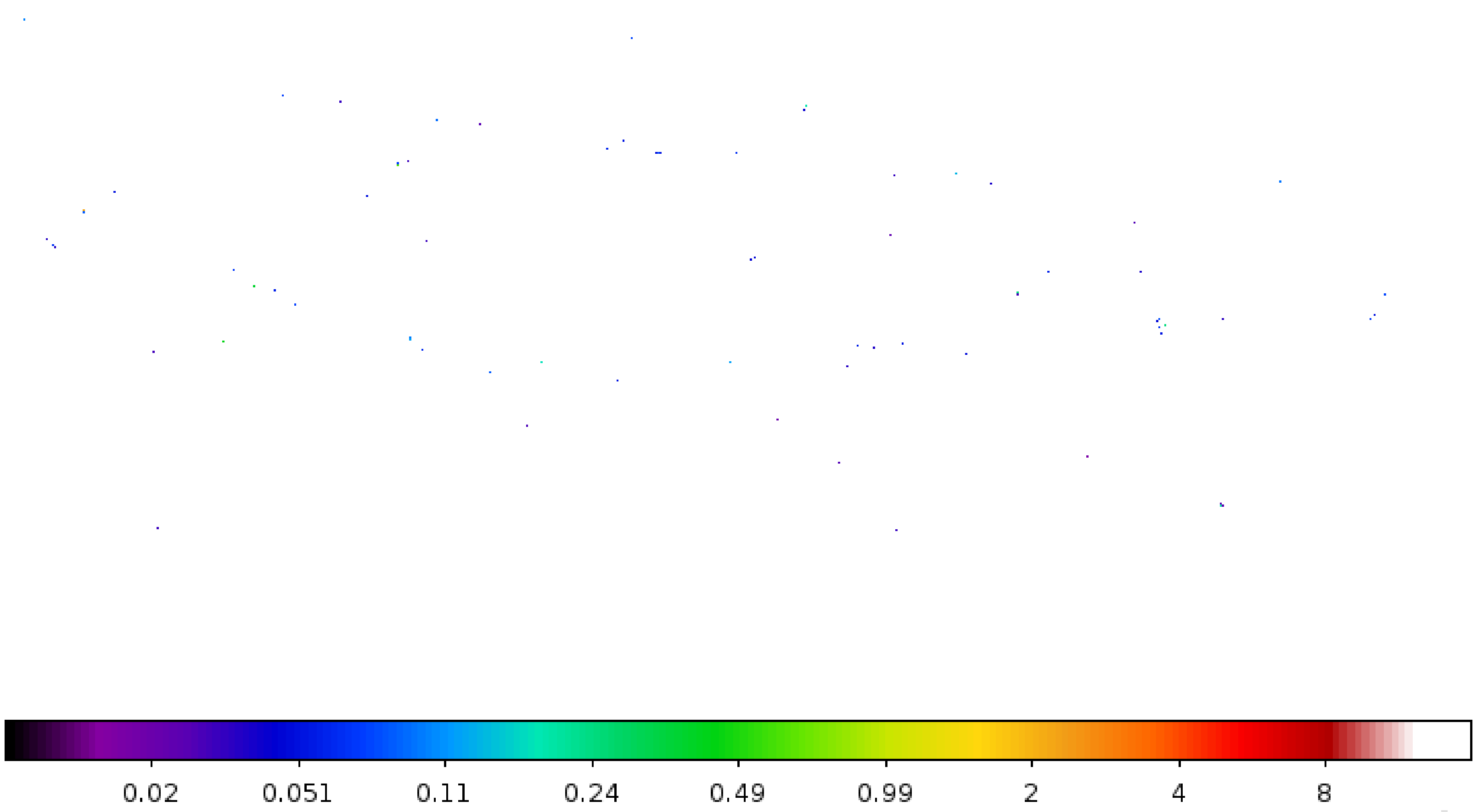

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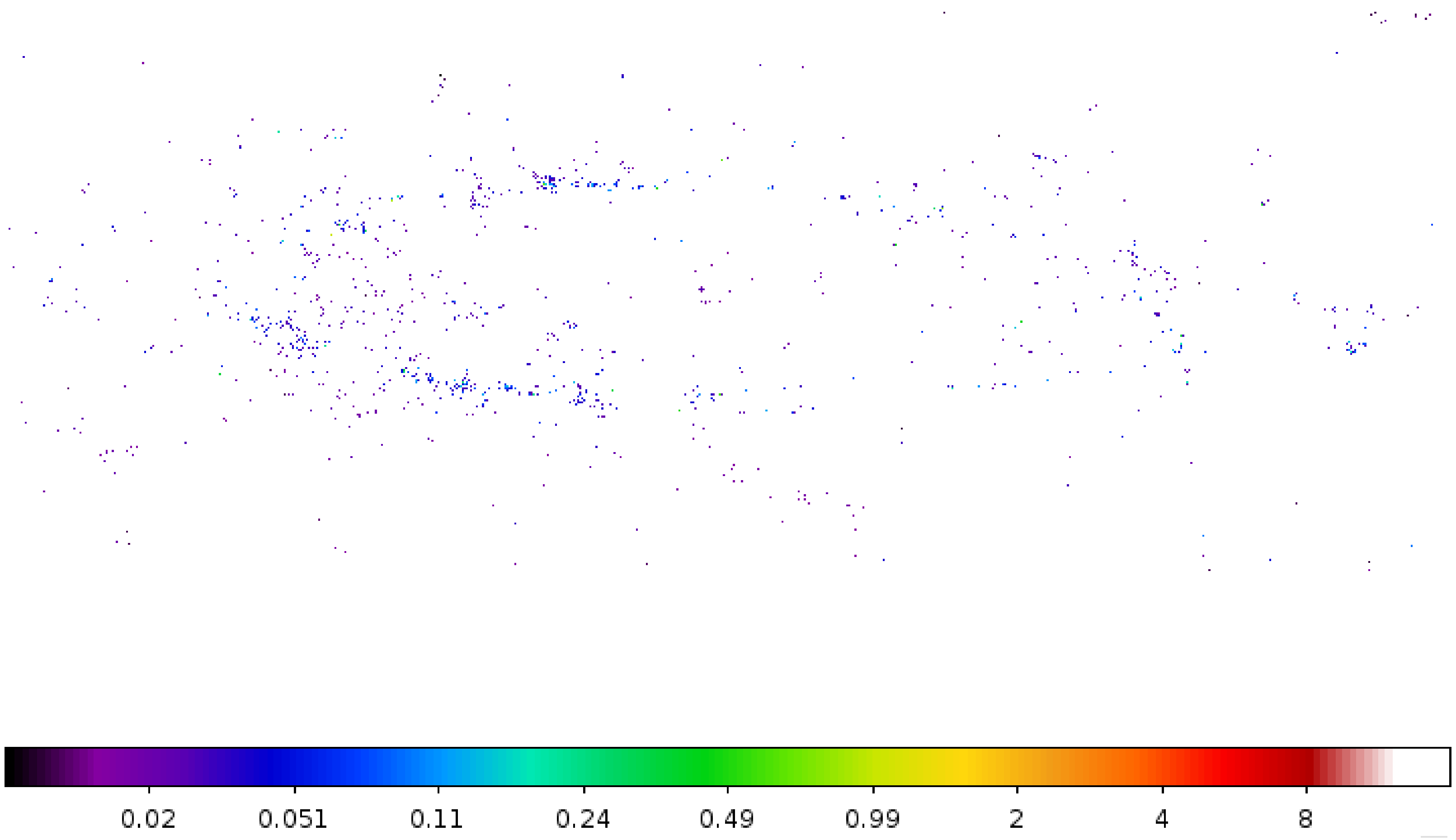
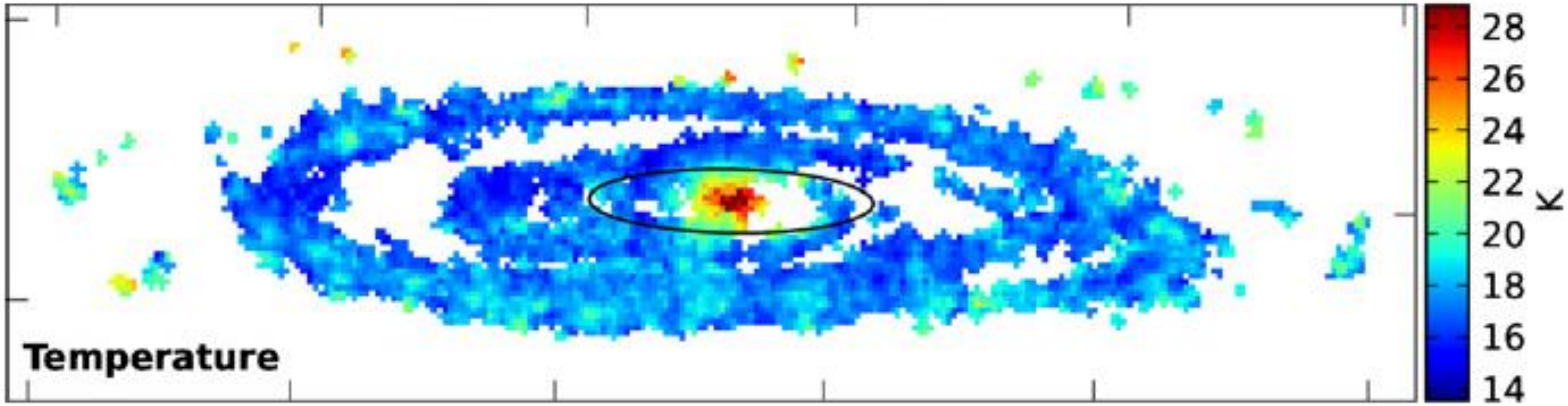
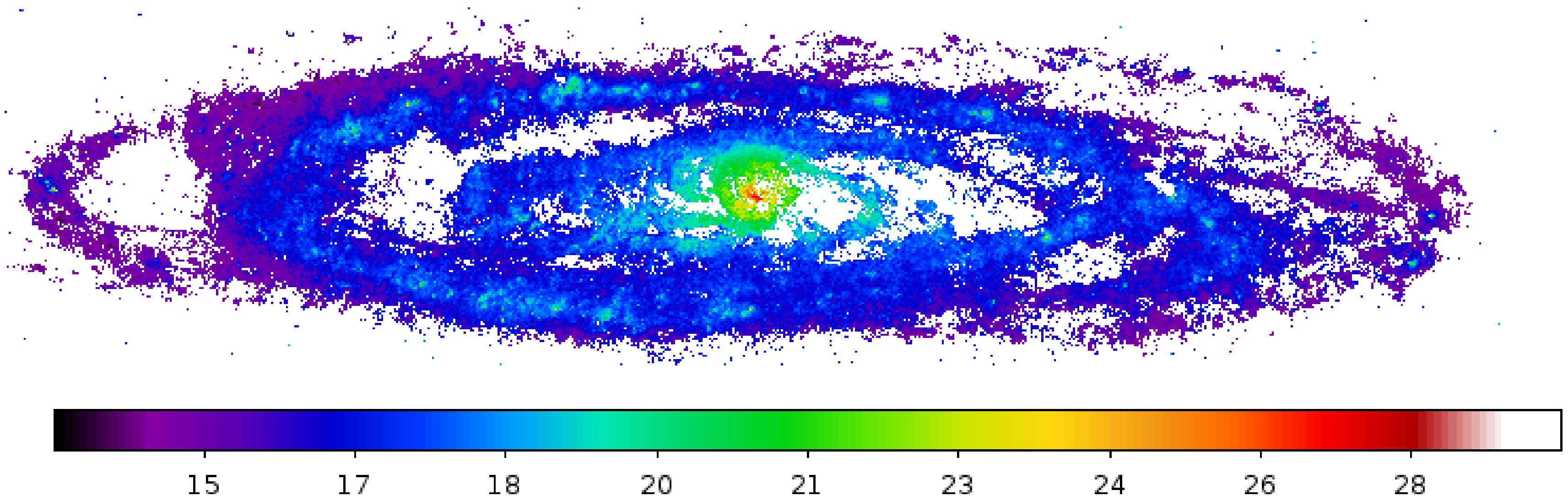


PPMAP temperature

Smith et al. (2012)

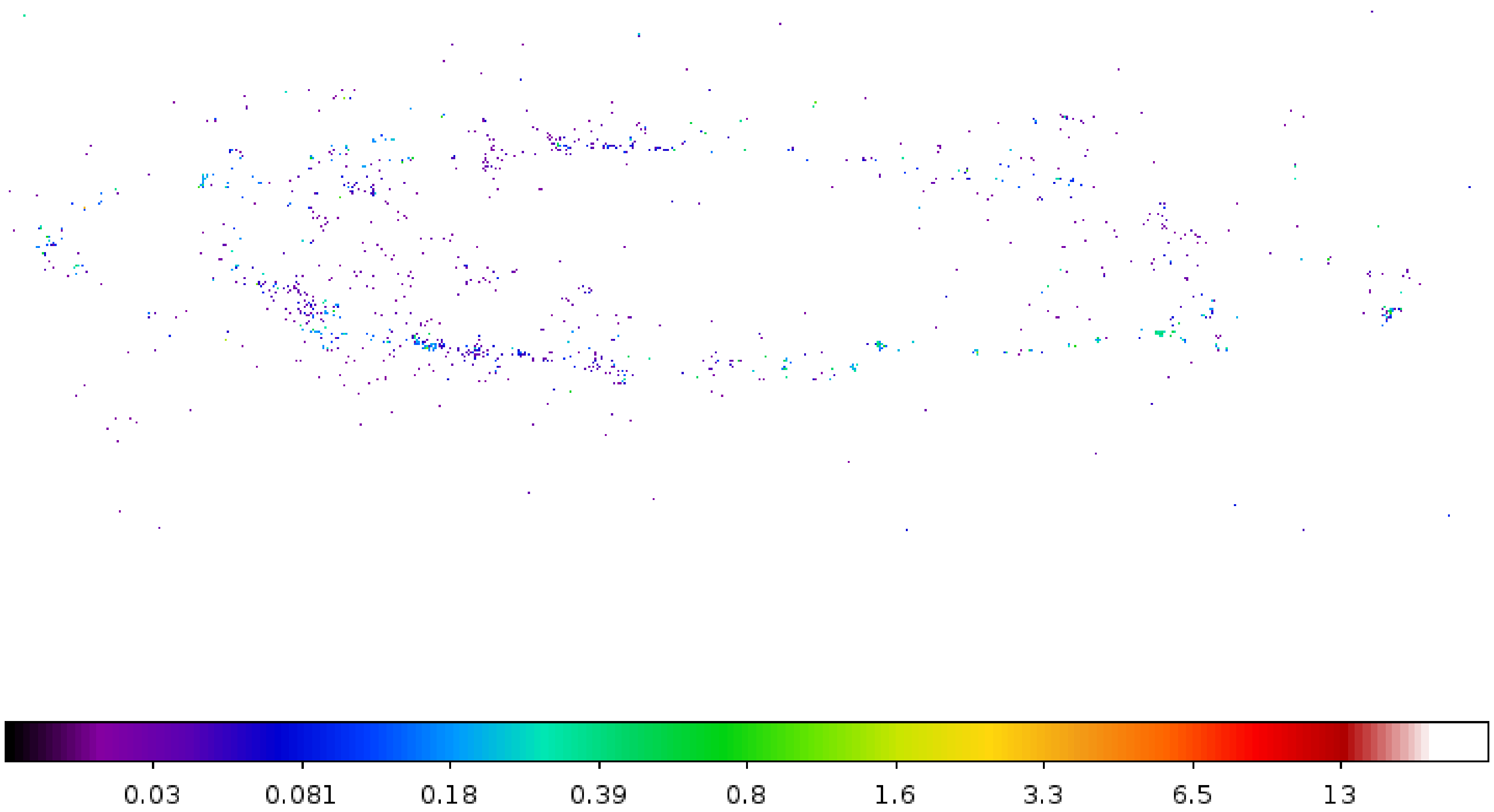


PPMAP



What about β?

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



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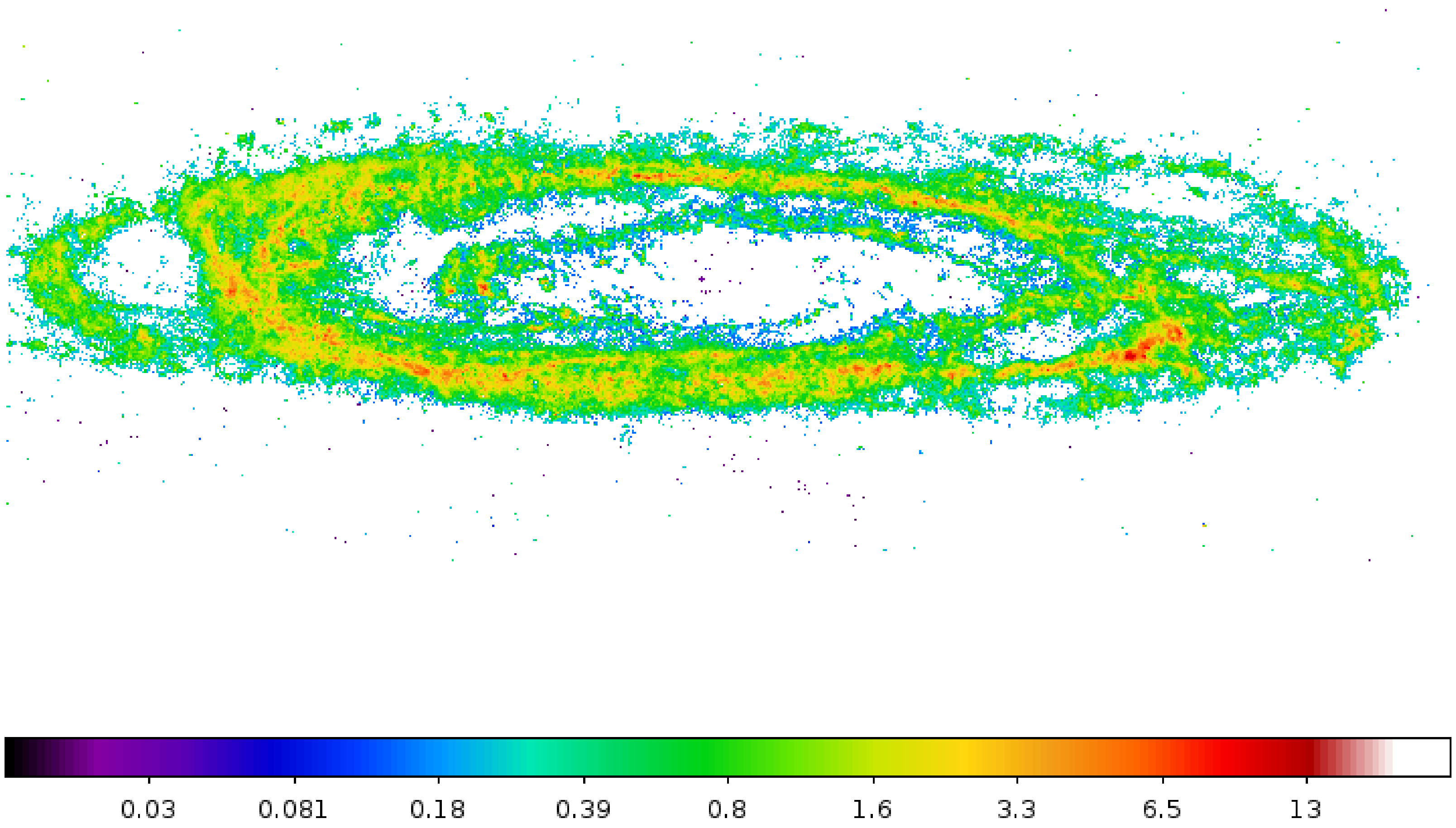

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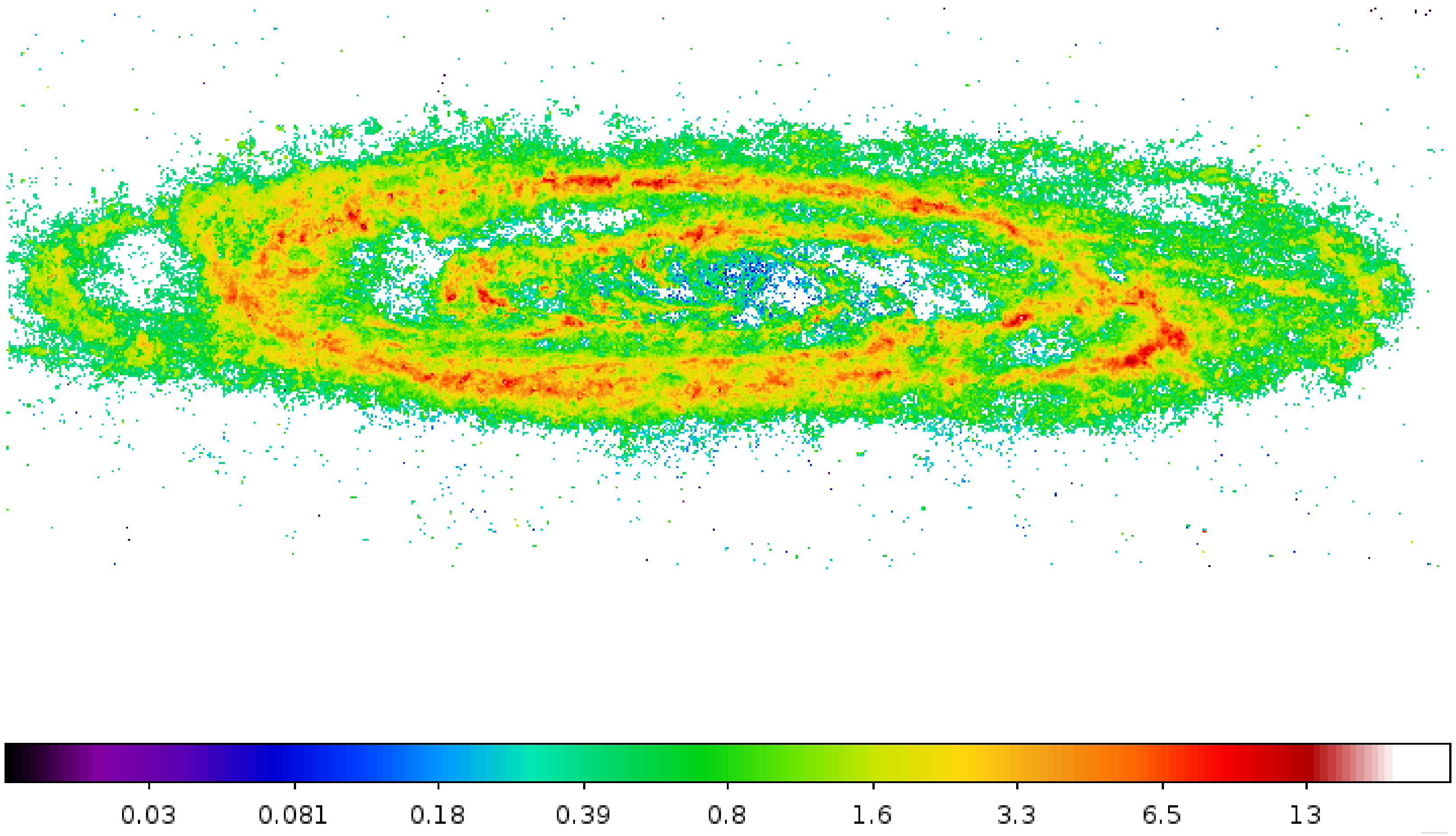

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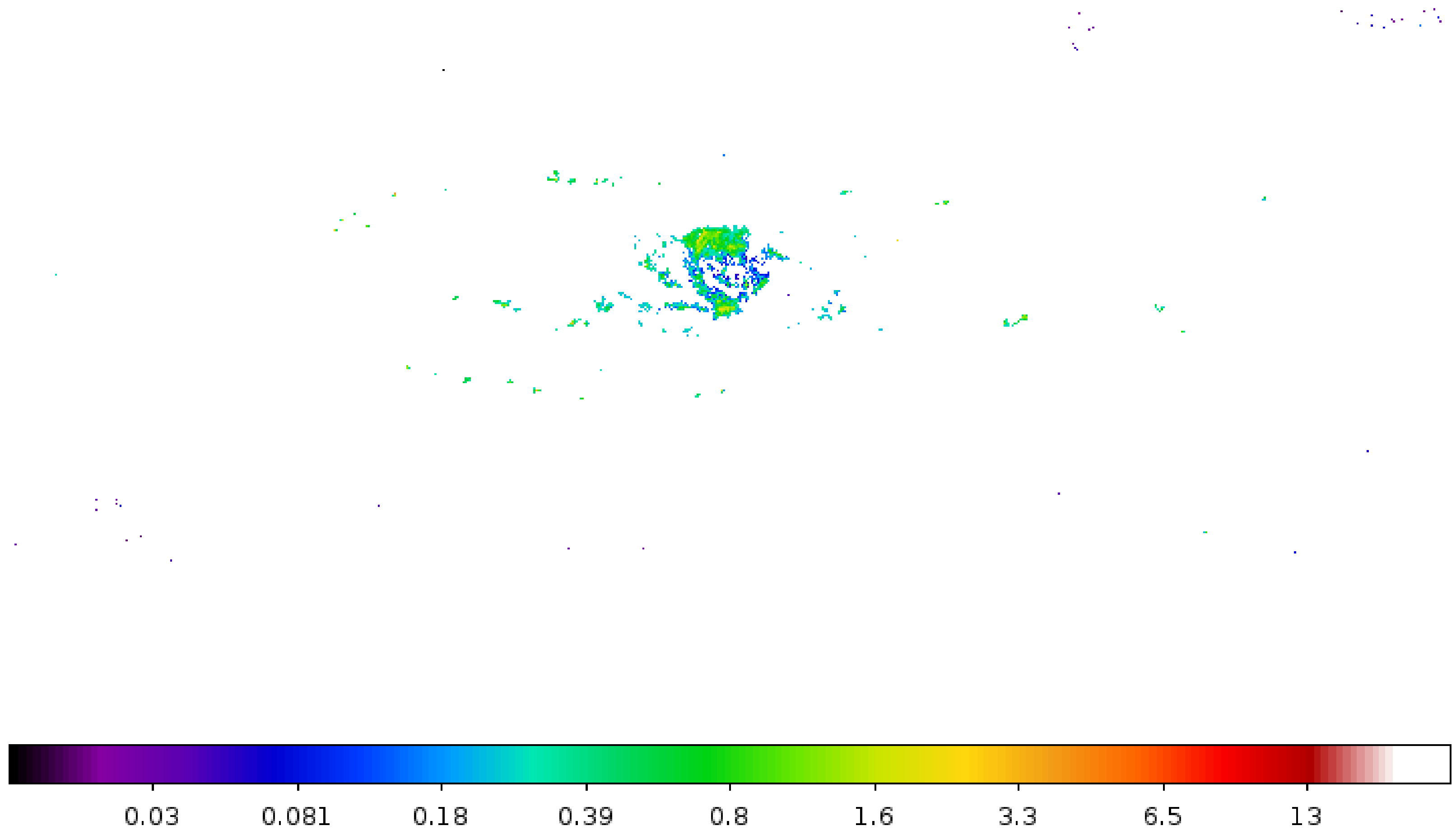
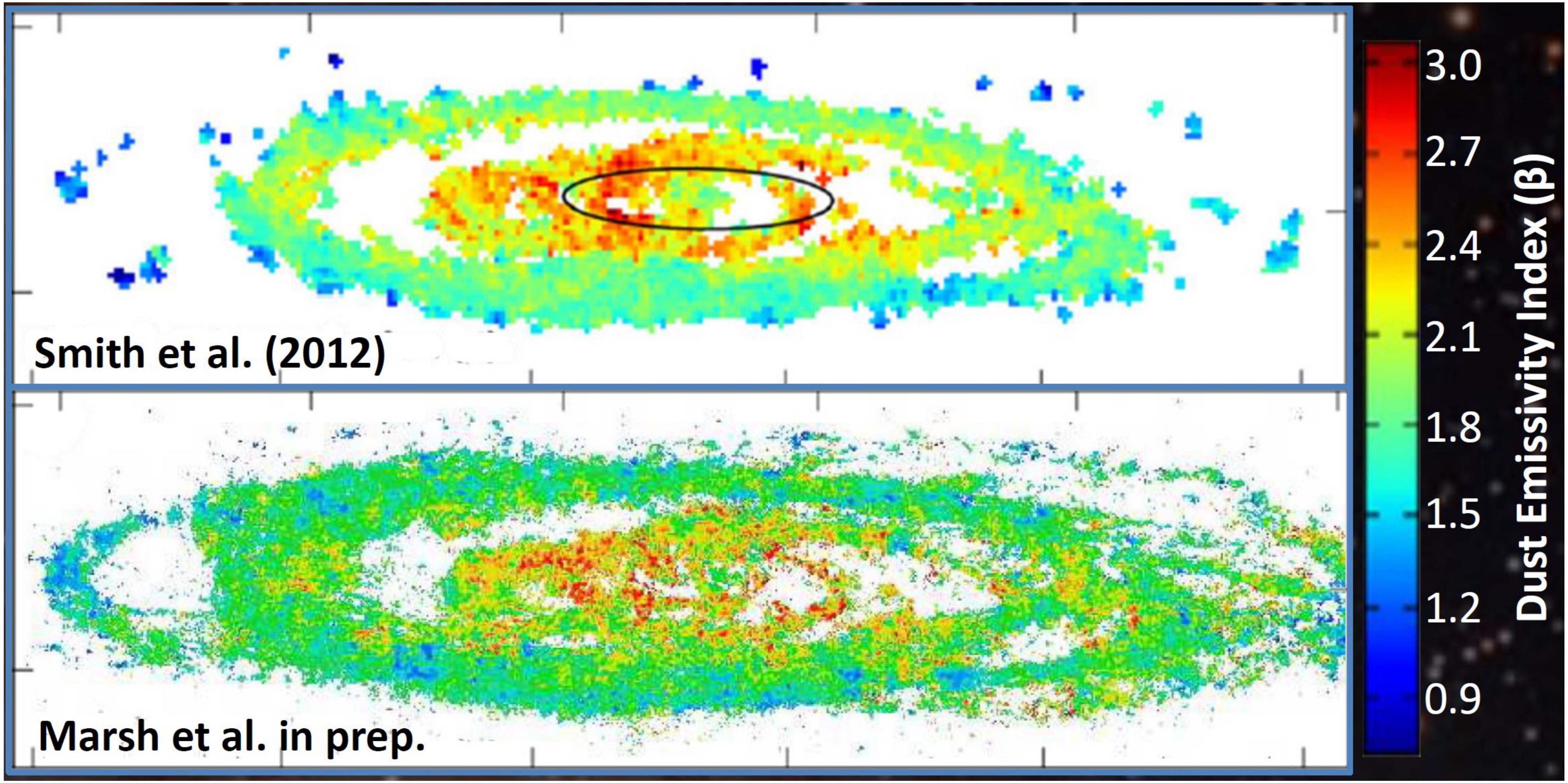
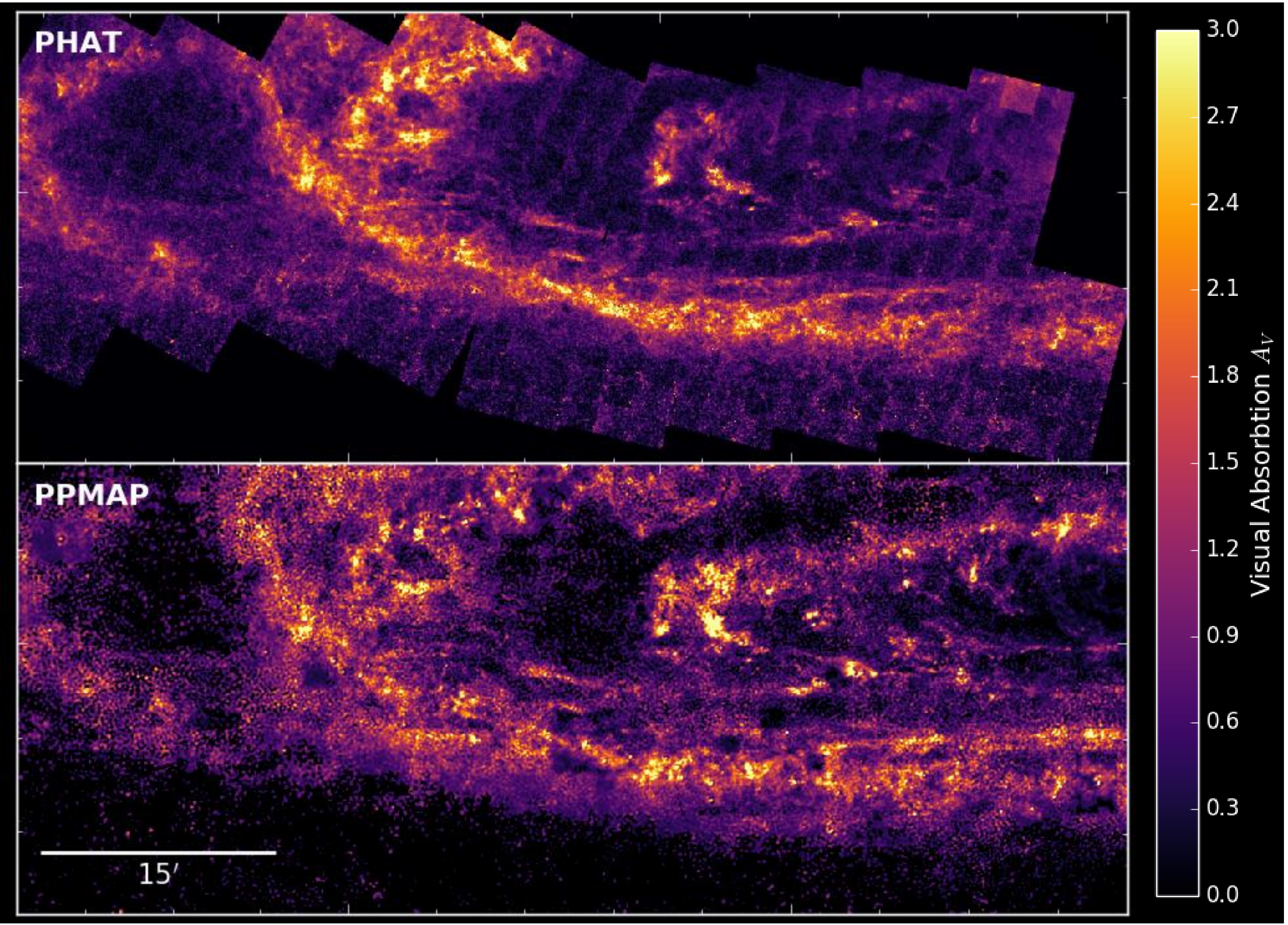


PPMAP – Mass-weighted β



PHAT vs PPMAP (Whitworth et al. in prep)



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

PPMAP – The future

- Planning on rolling out PPMAP to M33 (where we already have deep SCUBA-2
- Run on a large reference sample (HRS/KINGFISH/Dustpedia etc…)

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

JCMT Andromeda Galaxy Survey

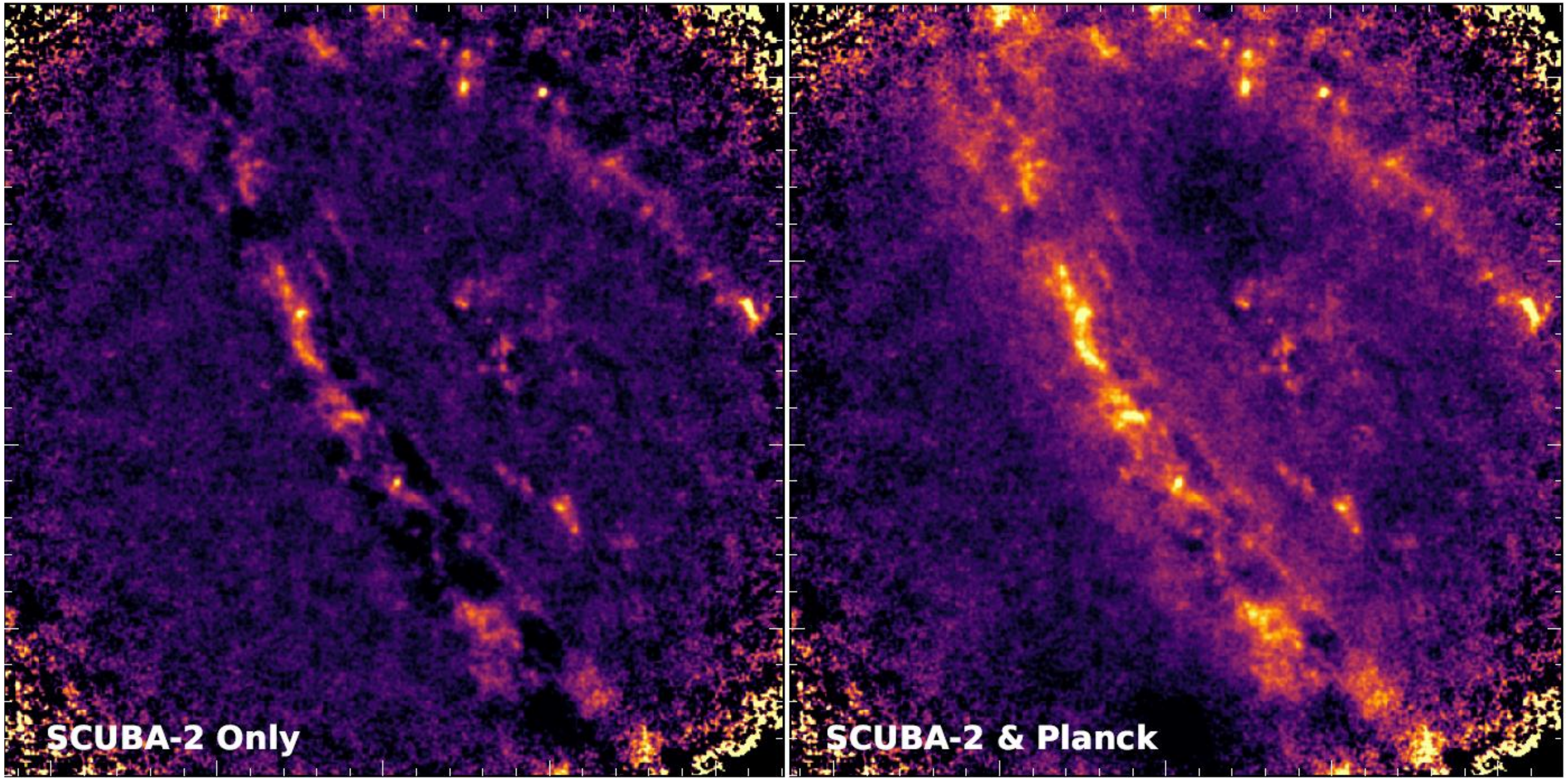
#HASHTAG

- 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?

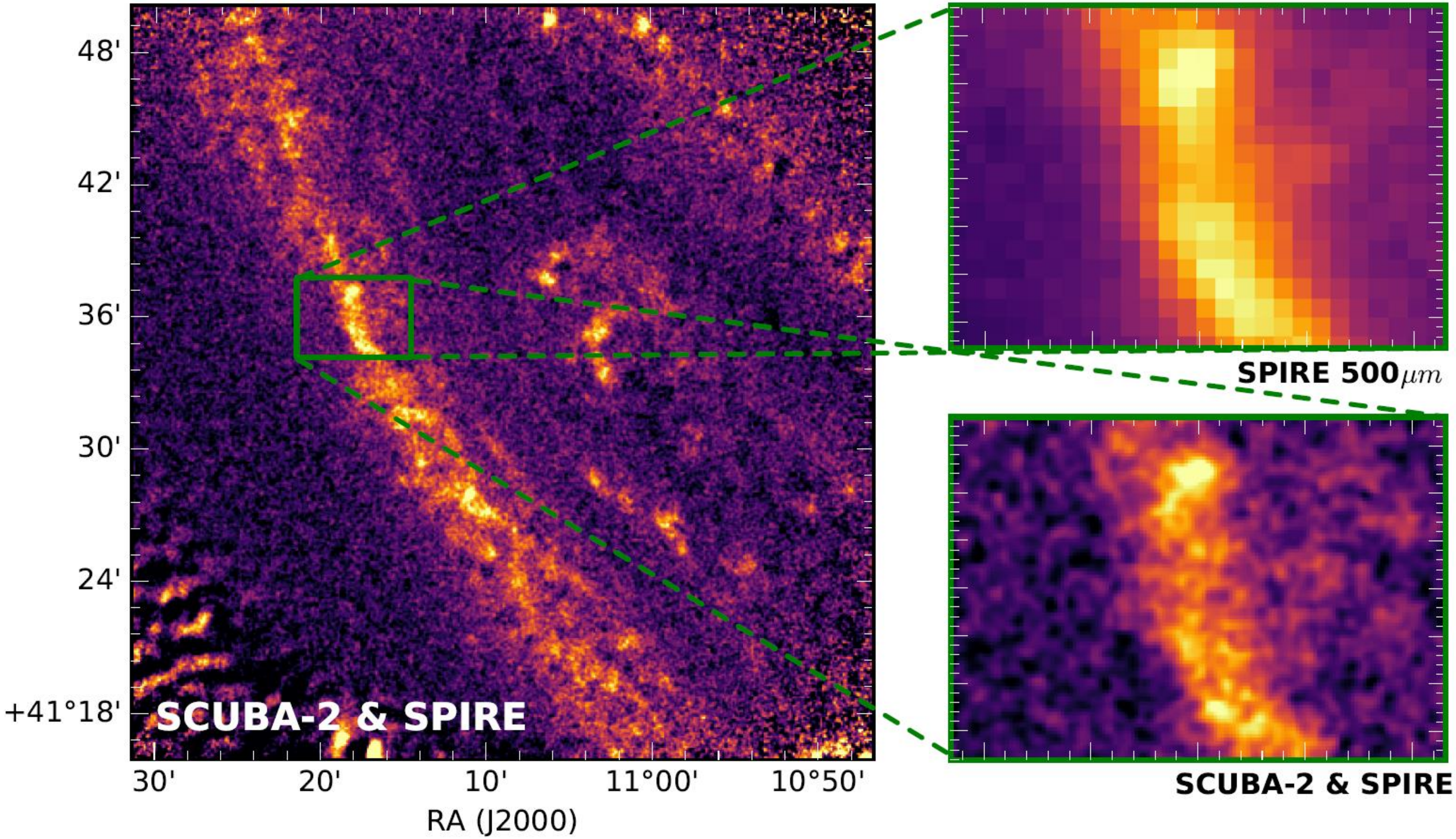
Large Scale Structure

- 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

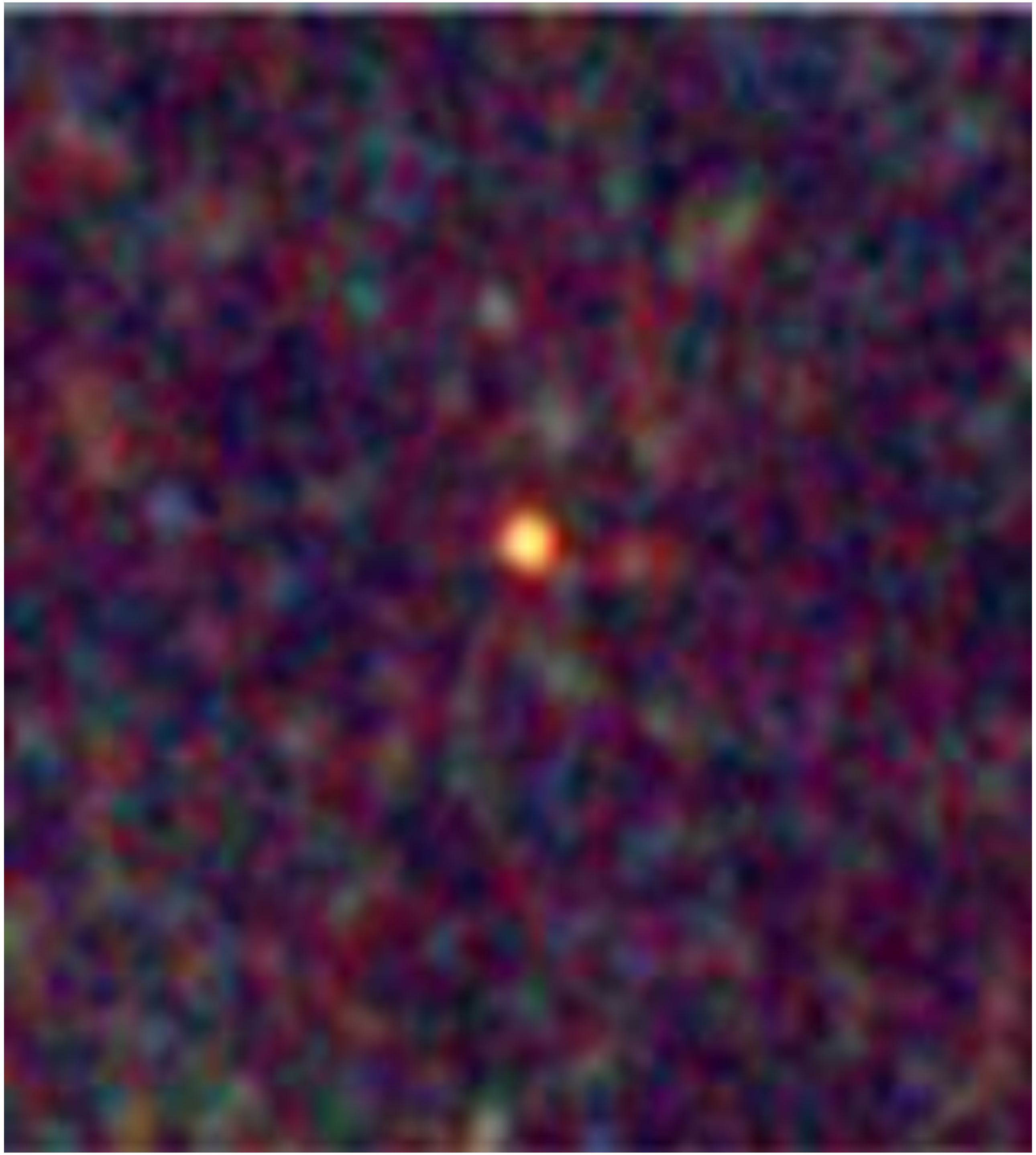


HASHTAG – some science goals

- 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

Strong Lensing

- Herschel was extraordinarily efficient at finding lenses
- Herschel can map large areas
- $z = 3.042$ (2 Gyr after big bang)
- Dye et al. (2015)
- ALMA observations 23 mas



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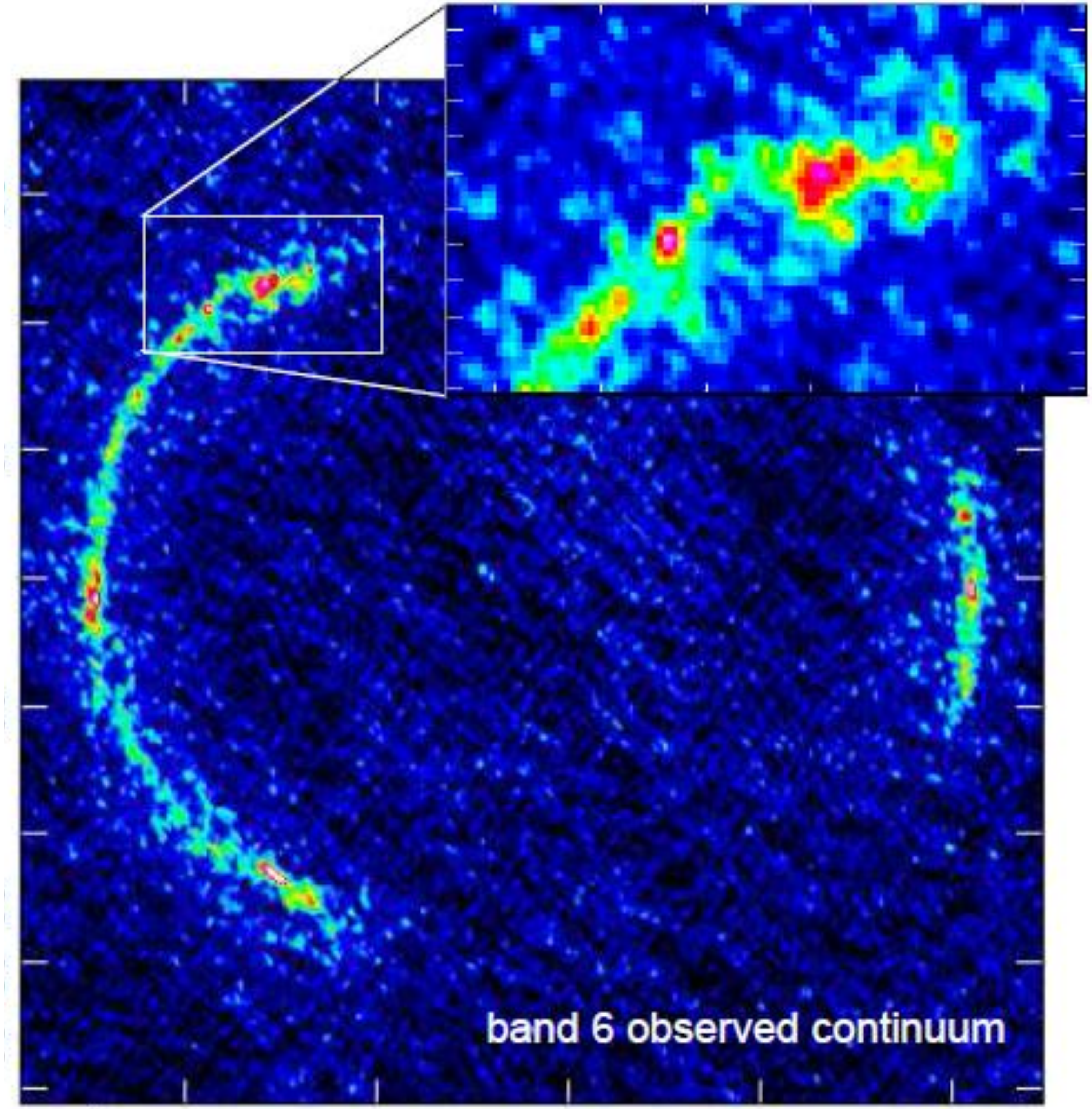
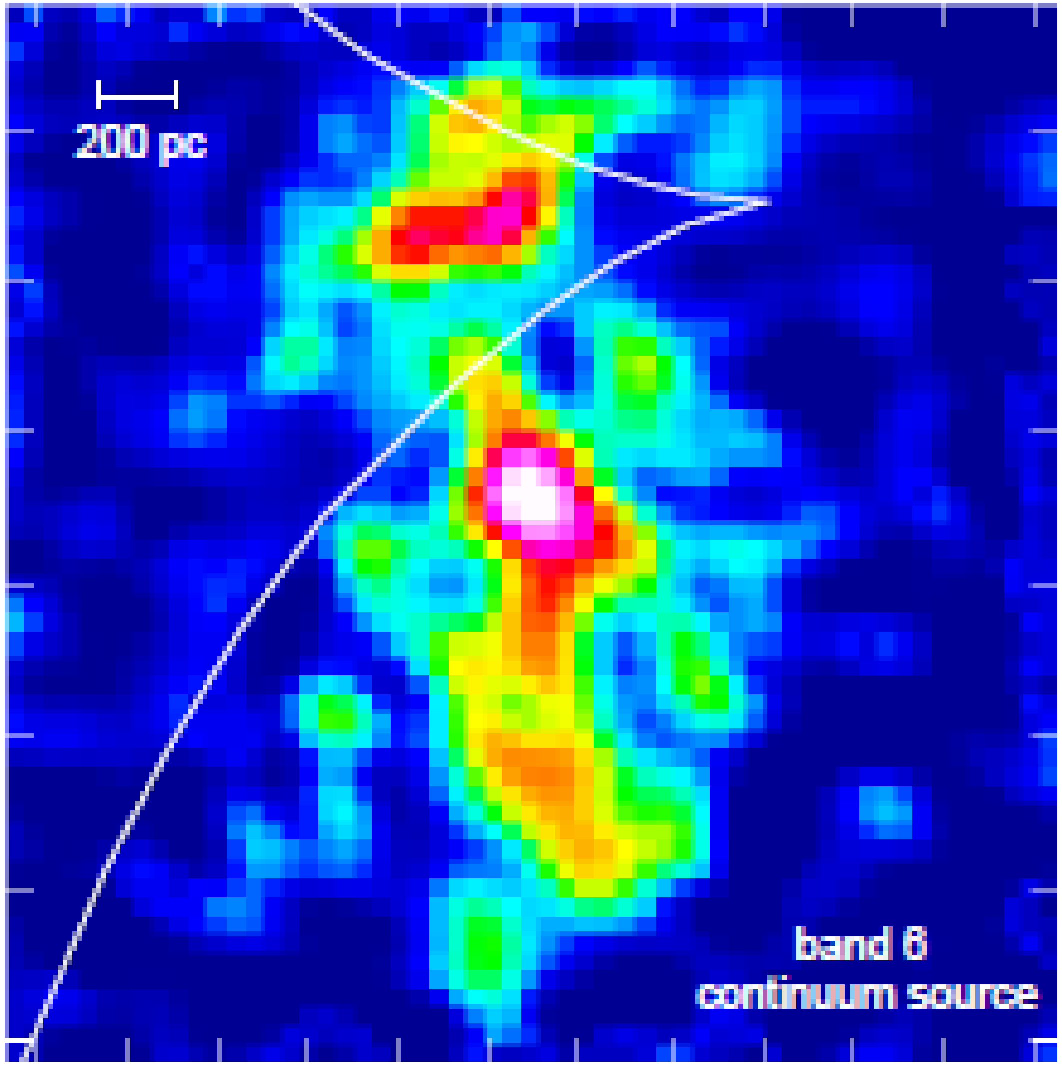


SDP 81



- Can reconstruct the actual source
- Sub 50pc physical resolution
- Dust shows an extremely clumpy distribution
- Clumps ~200pc in size
- 500 $M_\odot/yr$

SDP 81 (2)

- Measure CO simultaneously
- Remarkably smooth velocity distribution
- Dynamics suggest disc is in stage of collapse