Dust emission in millimeter wavelengths

Cooling of the interstellar medium in NGC6946

PRELIMINARY RESULTS

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OUTLINE

- Introduction
- NGC 6946: properties
- NGC 6946: observation
- Radio continuum component
- Dust properties
- Regional analysis
- SED modelling

COLLABORATORS

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- The rest of the IMEGIN team
- On behalf of the NIKA2 collaboration

INTRODUCTION

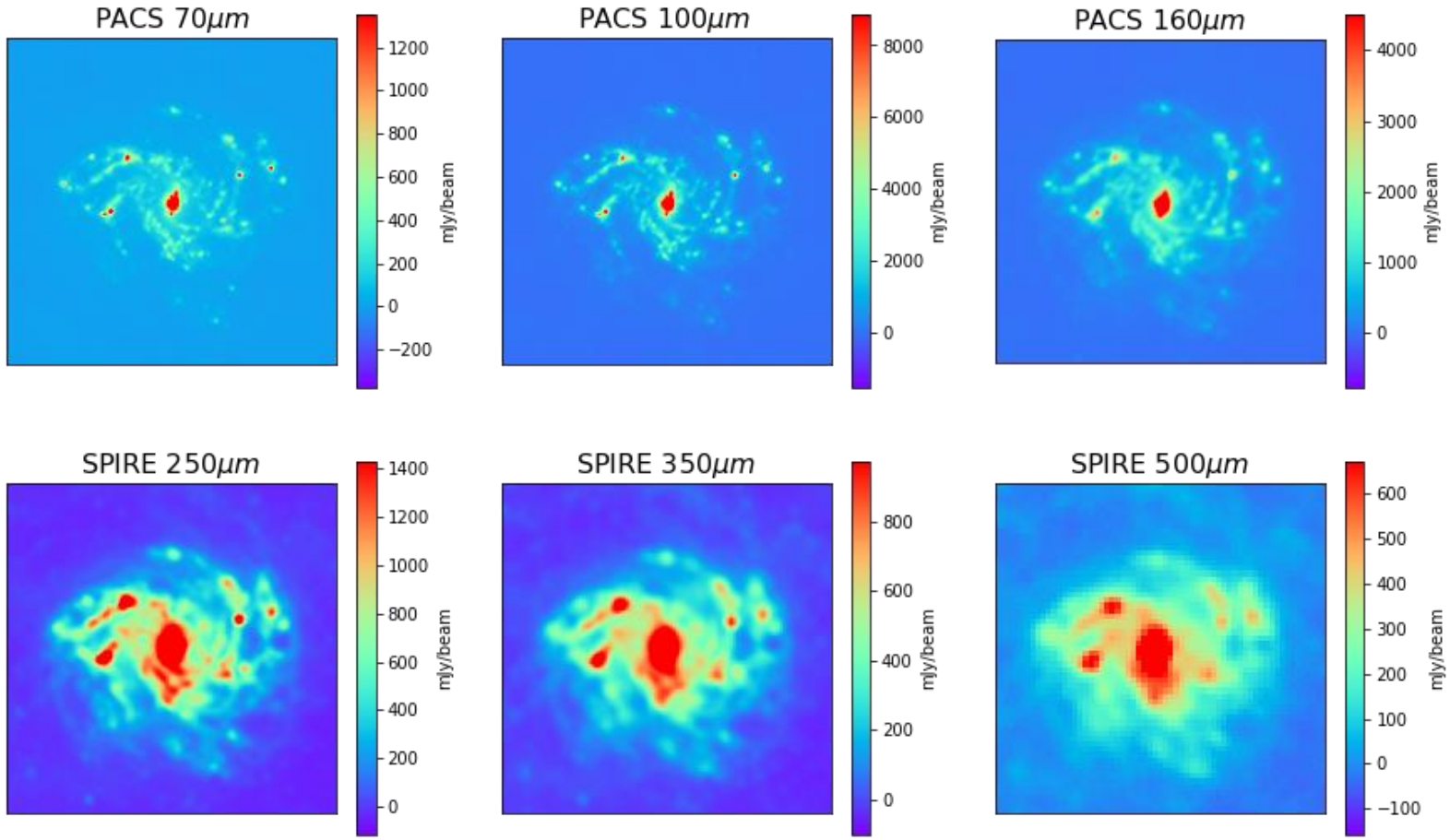
- **IMEGIN project** (**I**nterpreting the **M**illimeter **E**mission of **G**alaxies with **I**RAM and **N**IKA2)
  - A Guaranteed time large project proposed to NIKA2 collaboration
  - About 200 observing hours on the 30m IRAM telescope
- Continuum emission in mm wavelengths contains contributions from:
  1. Thermal emission from dust
  2. Thermal Free-free emission from ionized gas
  3. Synchrotron nonthermal emission from cosmic rays propagating through magnetic field

- Goals:
  - To relate these processes to star formation
  - To constrain galaxy Spectral Energy Distributions (SED) spatially to determine evolution of the dust emissivity and gas-to-dust ratio

- NIKA2 properties:
  - Field of view (FOV) of 6.5 $arcmin$
  - resolution of 11.1 $arcsec$ (1.15 mm) and 17.6 $arcsec$ (2 mm), *Perotto+2020*.

NGC6946: PROPERTIES

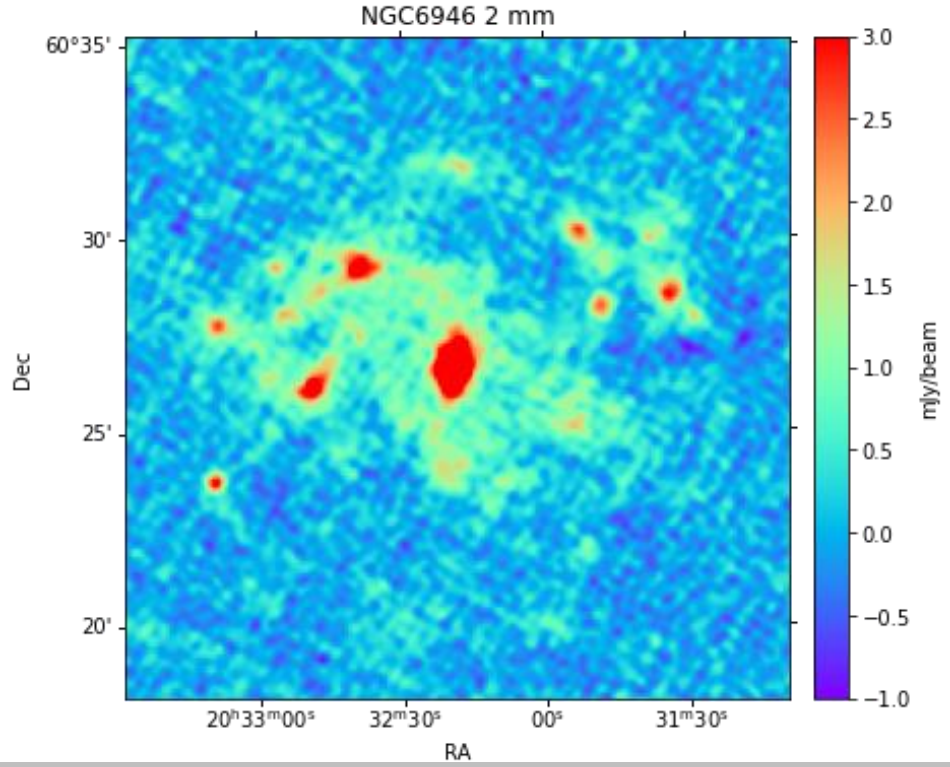
- Face-on spiral, distance= 6.8 Mpc, (pc=parsec)
  - Resolution of ~400 pc and ~600 pc achievable with NIKA2 .
- Resolved nucleus, interarm and diffuse disk
- CO(2-1) observed with HERA in HERACLES survey at 13 $arcsec$ resolution, *Leroy+2009* .
- Numerous dust continuum maps exist from Spitzer and Herschel, *Aniano+2012*.
- Decomposed thermal free-free and non-thermal synchrotron maps emission exists, *Tabatabaei+2013*.

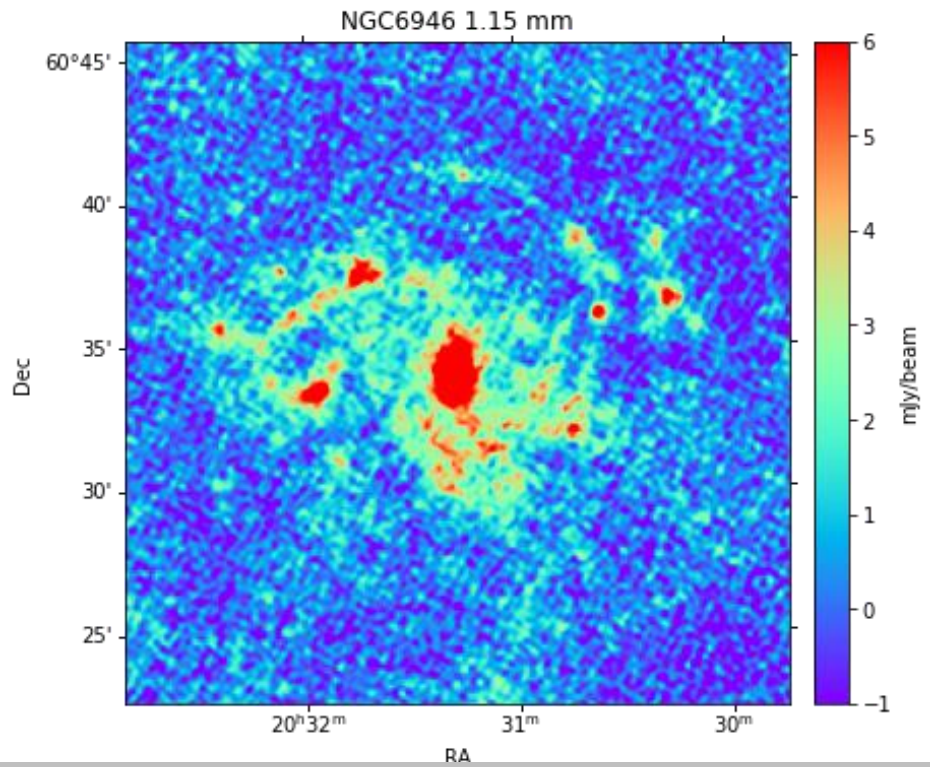


DustPedia archive, Clark+2018

NGC6946: OBSERVATION

- Observation with NIKA2 in Jan and Feb 2020 and March 2021 (preliminary).
- A total of ~29 hours of observation and 123 scans.
- Reached rms: 0.8 mJy/bm (1.15mm) and 0.27 mJy/bm (2mm)
- Original resolution of 12 $arcsec$ (1.15mm) and 18 $arcsec$ (2mm)





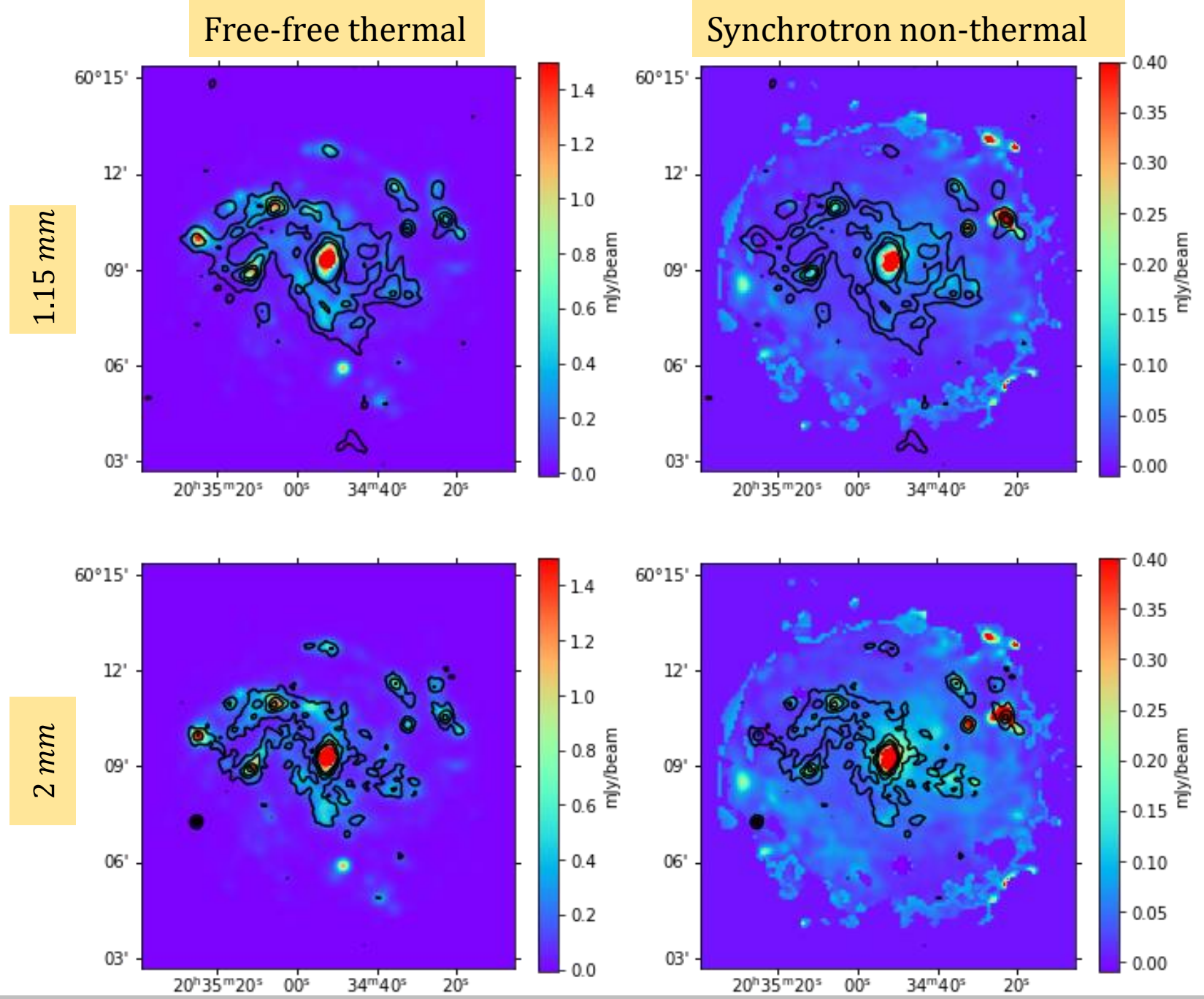
RADIO CONTINUUM (RC) COMPONENT

- Thermal and nonthermal decomposition:

  Thermal Radio Tracer (TRT) method, from *Tabatabaei+2013*

- Contours of observed flux from NIKA2

  (3, 6, 9 and 12 σ rms levels)

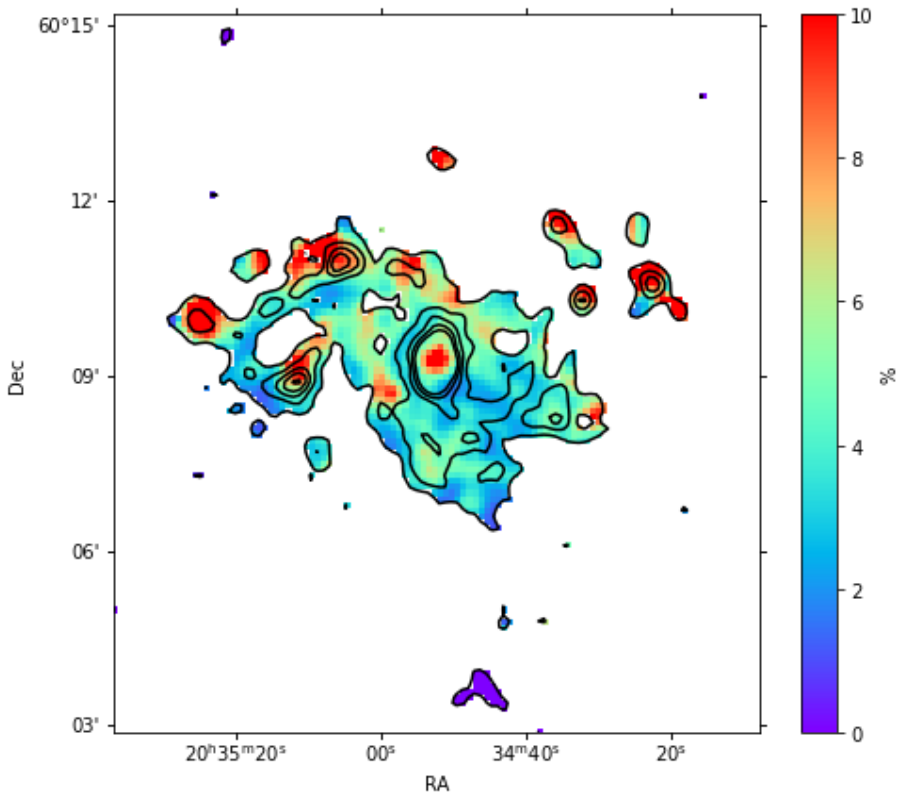


RADIO CONTINUUM COMPONENT

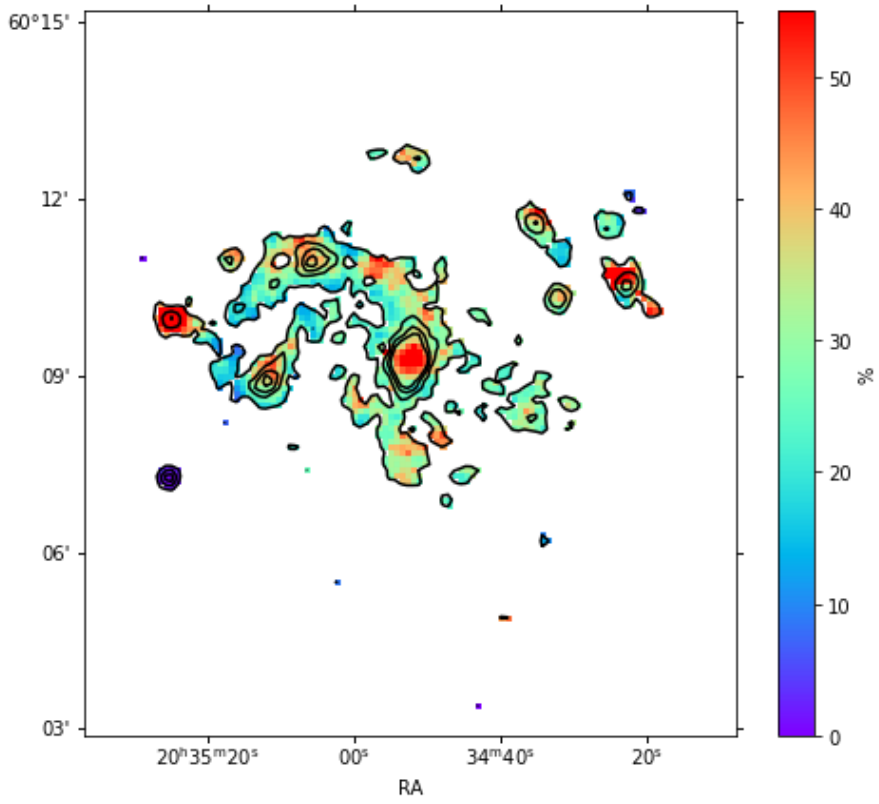
- Percentage of radio continuum component (thermal free-free + nonthermal synchrotron) with respect to flux observed with NIKA2

  Contours of observed NIKA2 overlaid.

1.15 mm



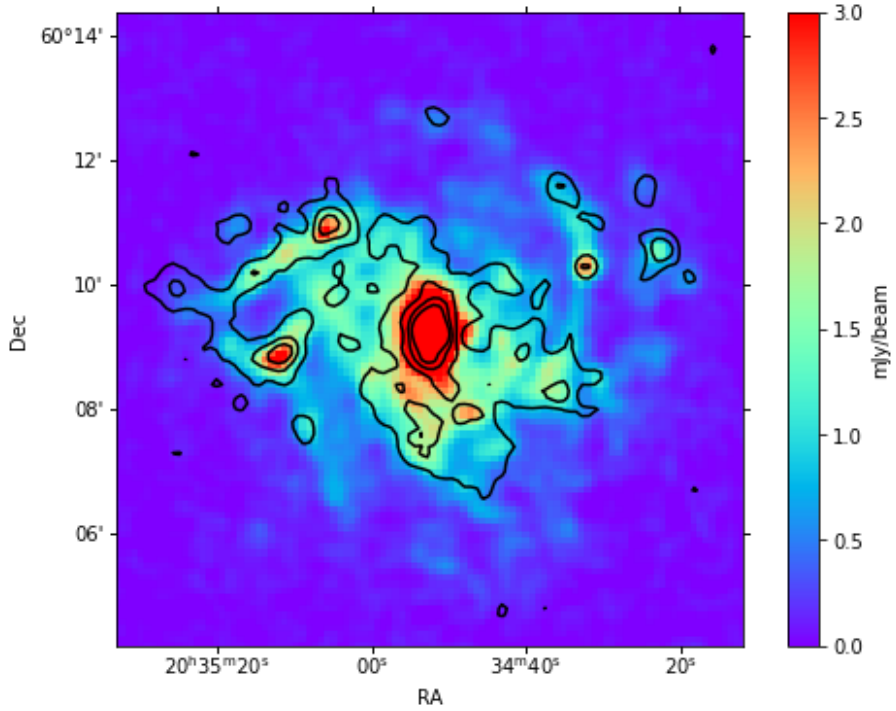
2 mm



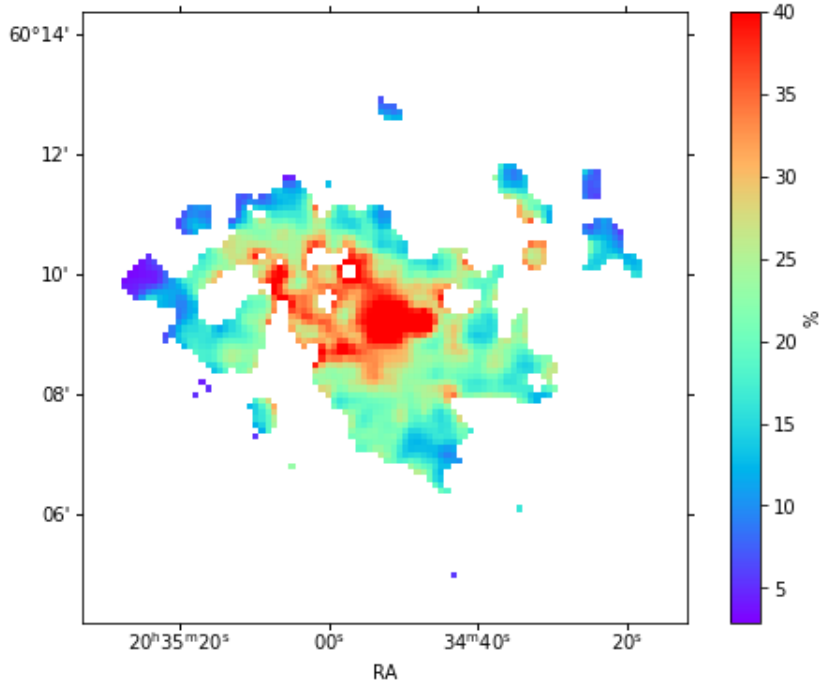
CO CONTAMINATION

- Contamination of CO(2-1) emission line ($\nu = 230.5\ GHz$) in NIKA2 $1.15mm$ maps
- Conversion of the line integrated intensity [in units $K\ km/s$] to pseudo-continuum flux [in units $mJy/beam$] using *Drabek+2012*

$$\frac{F_\nu}{\text{mJy /beam}} = \frac{2k\nu^3}{c^3}\ \frac{g_\nu(line)}{\int g_\nu dv} \int T_{\text{MB}} dv$$



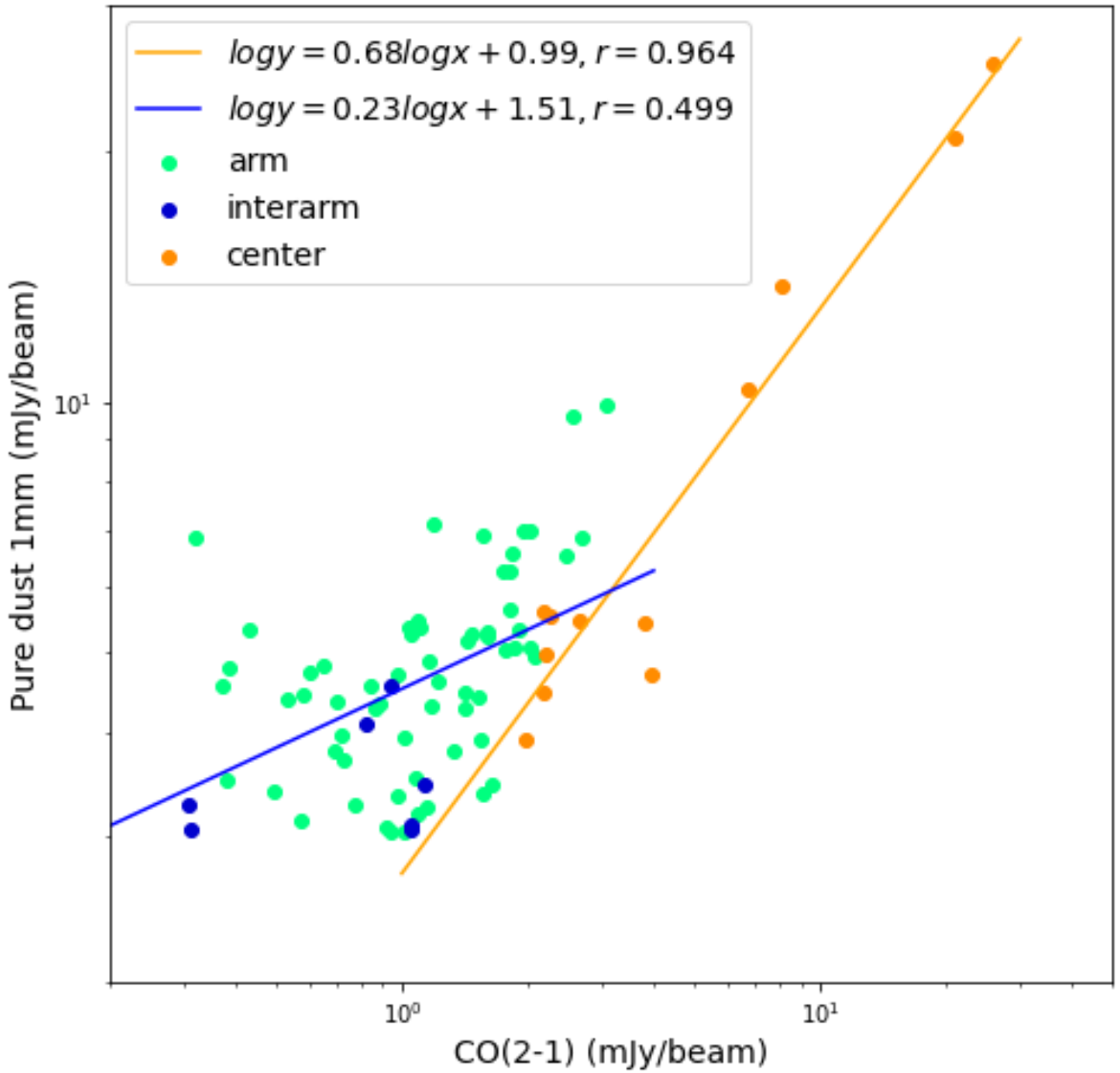
CO(2-1) emission observed as a part of HERACLES survey, overlaid contours with pure dust emission at 1.15mm with levels 3,6,9 and 12 σ RMS.



Percentage of CO(2-1) emission in the observed NIKA2 1.15 mm emission, shown for pixels with values larger than 3 σ RMS of both maps.

DUST TO GAS EMISSION RATIO

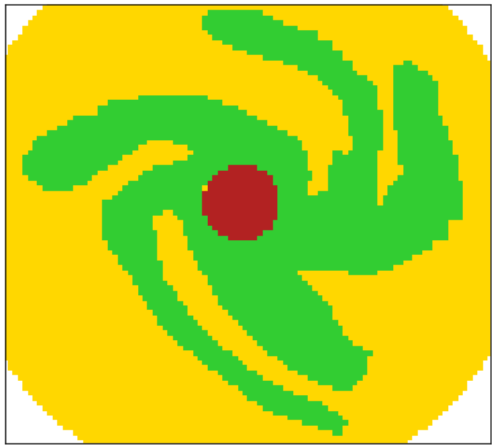
- A larger dust-to-molecular gas (emission) ratio in central region with respect to arm and interarm regions.
- Cause of different slopes in the disk and inner region:
  - Different heating sources of dust and molecular gas in the disk and central region
  - Common heating source in central region
  - Distinct heating source of dust in disk: old stars and diffuse interstellar radiation field

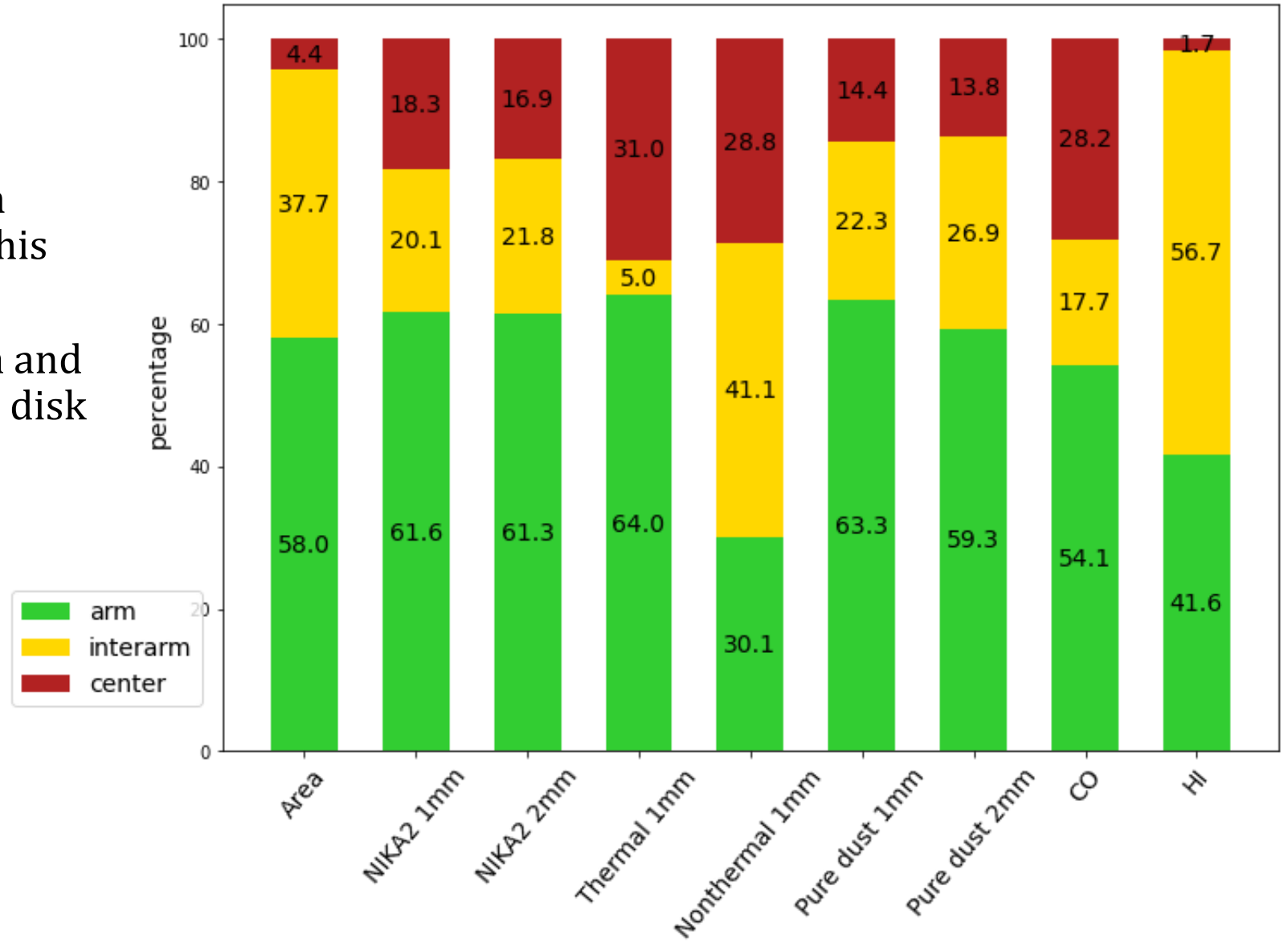


Pure dust emission at $1.15mm$ *plotted against CO(2-1) emission for pixels with values larger than 3* σ *RMS and separated by one resolution element.*

REGIONAL ANALYSIS

- A modified version of the mask introduced in *Bigiel+2020*.
- Contribution of different emission components for three regions of this galaxy, center, arm and interarm
- Different heating sources of warm and cold dust in $1mm$ and $2mm$ in the disk



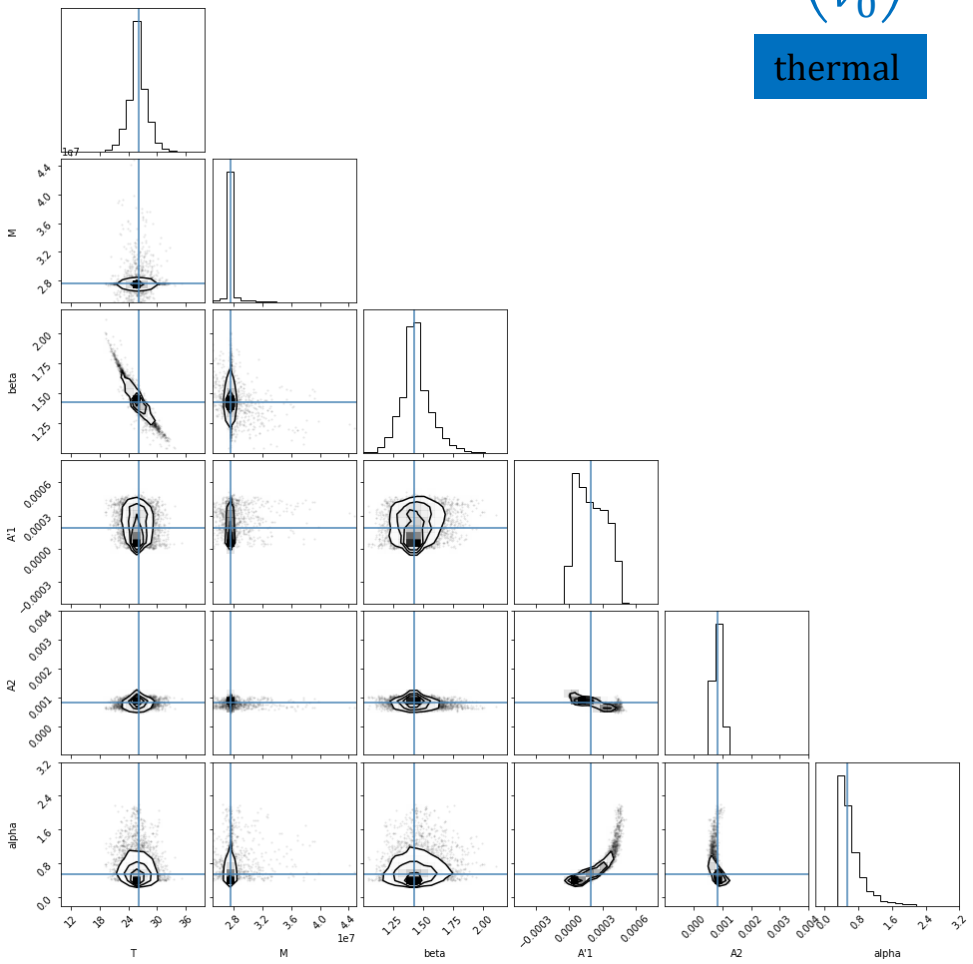


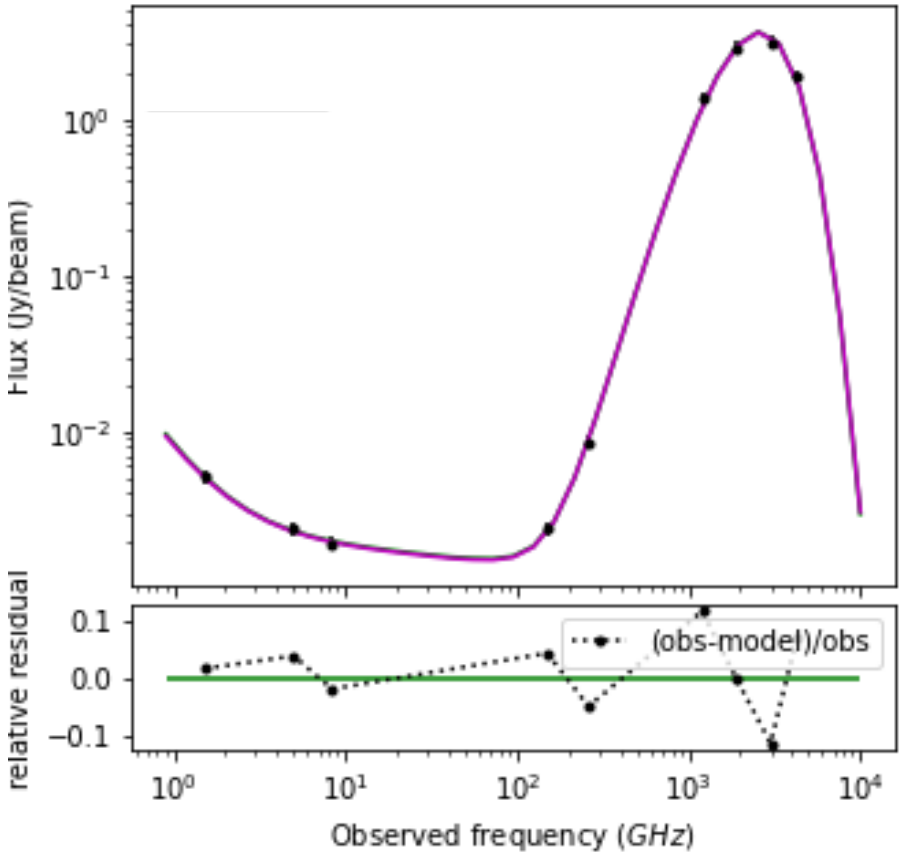
SED MODELLING

- Fitting method: Bayesian MCMC method, using Python *emcee*, *Foreman-Mackey+2013*.
- Simultaneously fit modified black body dust model and radio emission, *Tabatabaei+2013*, *Tabatabaei+2017*.

$$F = A_1' \left(\frac{\nu}{\nu_0}\right)^{0.1} + A_2 \nu_0^{-\alpha} \left(\frac{\nu}{\nu_0}\right)^{-\alpha} + \kappa_0 \left(\frac{\nu}{\nu_0}\right)^{\beta} \times \frac{M}{D^2} \times B(\nu, T)$$

thermal | nonthermal | dust

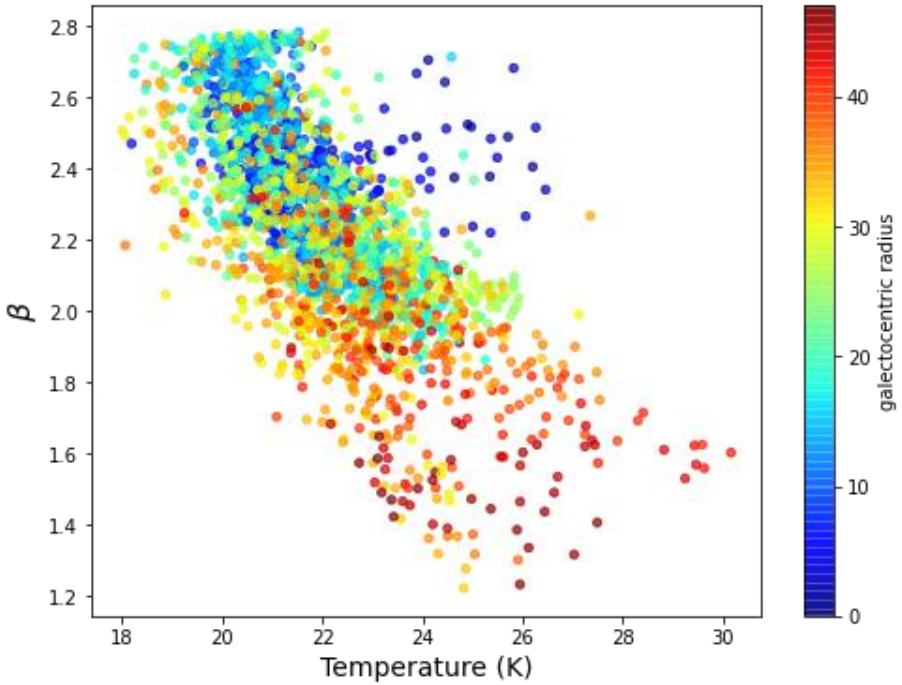


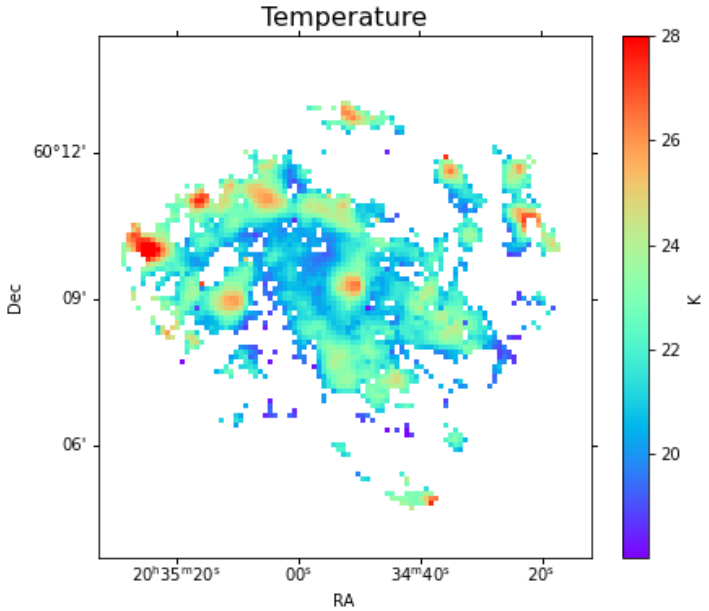


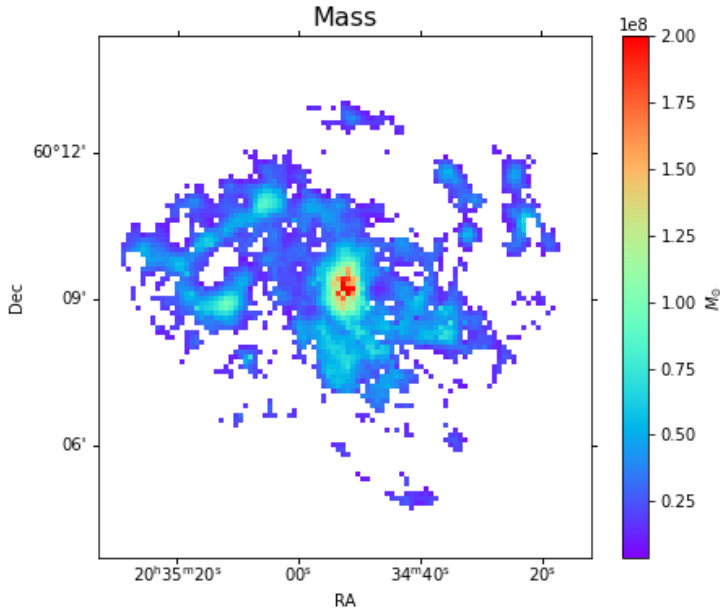
Telescope	λ
Herschel – PACS	$70\ \mu m$ $100 \mu m$ $160 \mu m$
Herschel - SPIRE	$250 \mu m$
NIKA2	$1.15\ mm$ $2\ mm$
VLA + Effelsberg	$3.6\ cm$ $6\ cm$ $20\ cm$

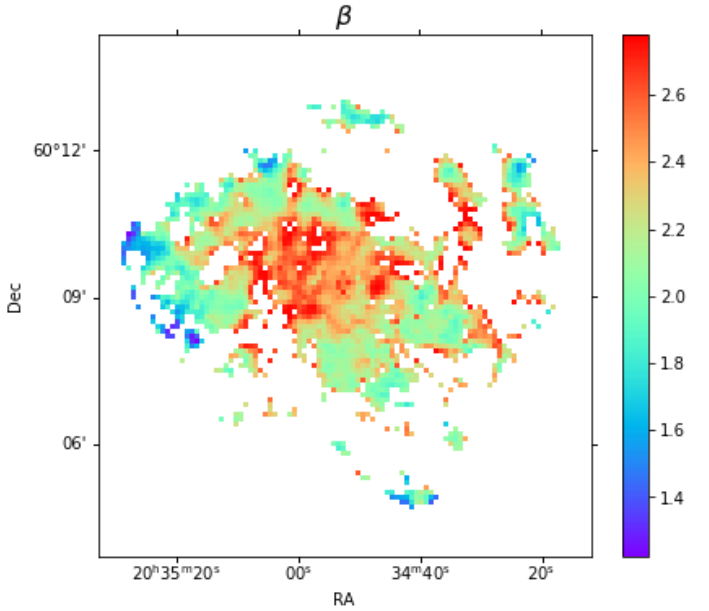
PARAMETER MAPS

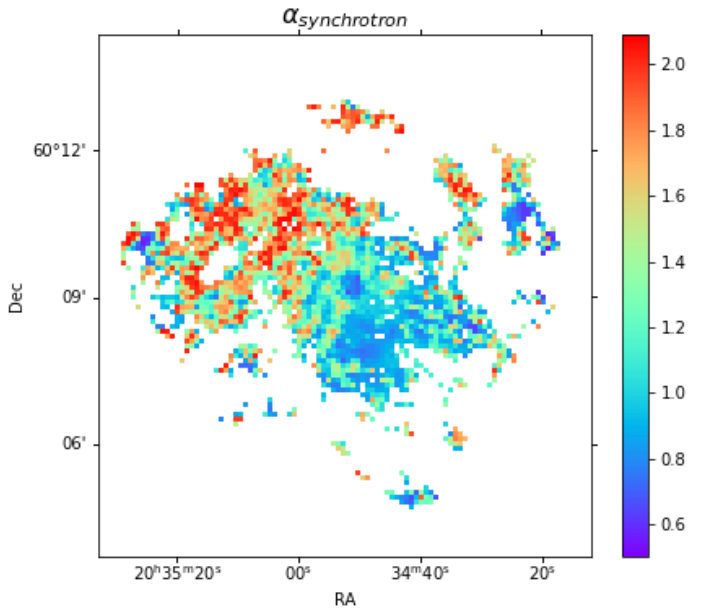
- Maps of temperature (T), dust emissivity index (β), dust mass (M), synchrotron spectral index (α)
- $T - \beta$ anti-correlation











SUMMARY OF IMPORTANT RESULTS

- In the center of NGC6946 the contribution of CO(2-1) is relatively high (~50%) .
- We report a tight correlation of CO(2-1) emission with pure dust emission in 1mm in central region of this galaxy. No such strong correlation is visible in arm and interarm regions.
- Using an MCMC Bayesian technique, we model the IR and RC SED pixel by pixel across the galaxy. The dust emissivity index is higher in the center than in the disk. There is an anti-correlation between beta and T in the disk.
- A radial gradient of dust mass is notable. In contrast, higher temperatures are found toward star forming regions.
- The synchrotron spectral index is flatter in star forming regions. Also an east-west gradient is notable.
- Larger dust emission in arm region in $1mm$ with respect to $2mm$ indicates different heating sources of cold and warm dust in the disk.