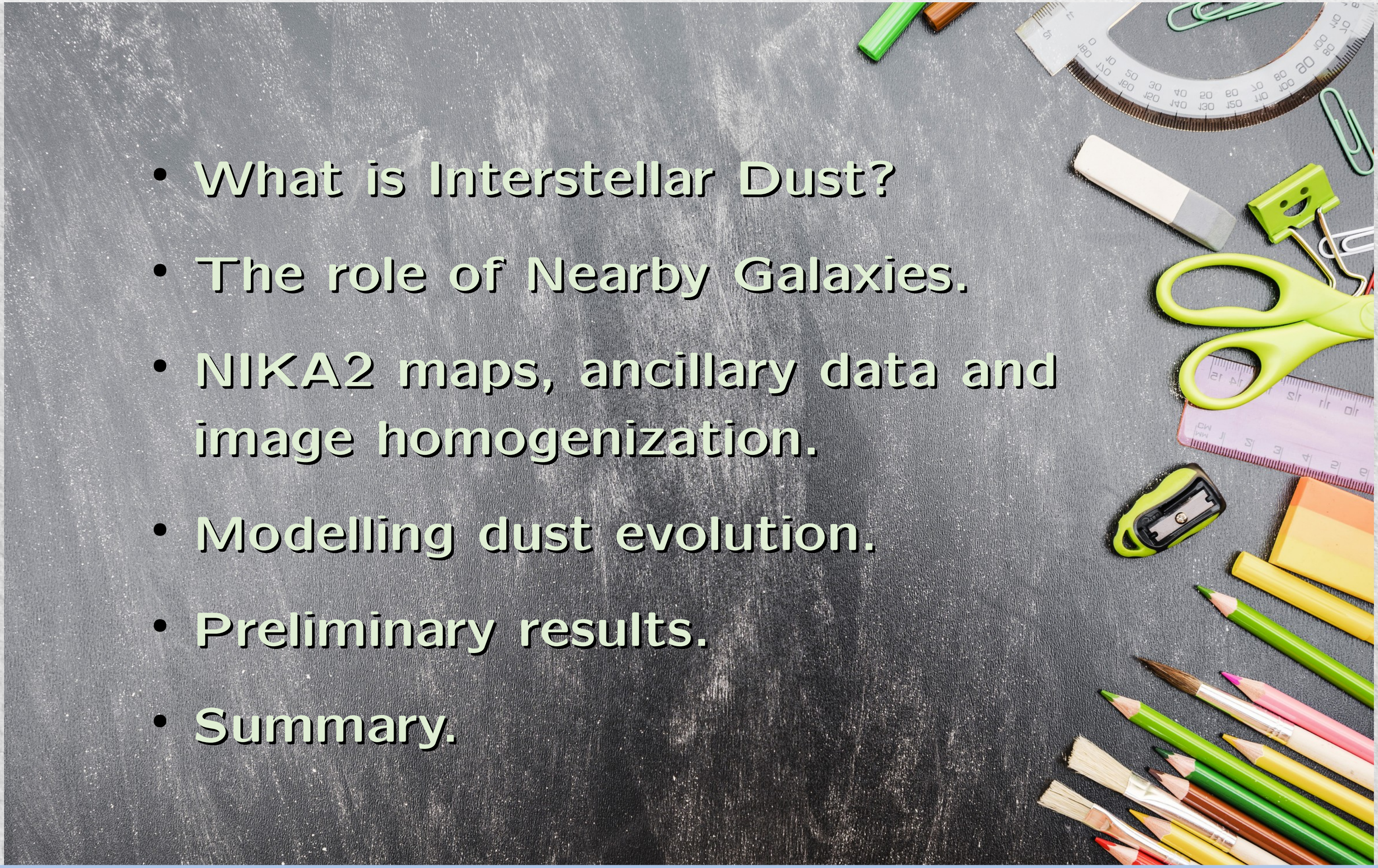
Dust millimetre emission in Nearby Galaxies with NIKA2 (IRAM-30m):

major challenges and latest results of the IMEGIN Large Program

A talk by **Lara Pantoni** (Postdoc at CEA/IAS, Paris-Saclay, France)
on behalf of the NIKA2 collaboration

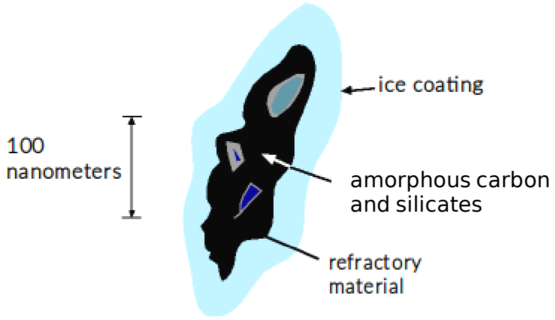
Local collaborators: F. Galliano (CEA), S. Madden (CEA), A. Jones (IAS), N. Ysard (prev. IAS)

Overview

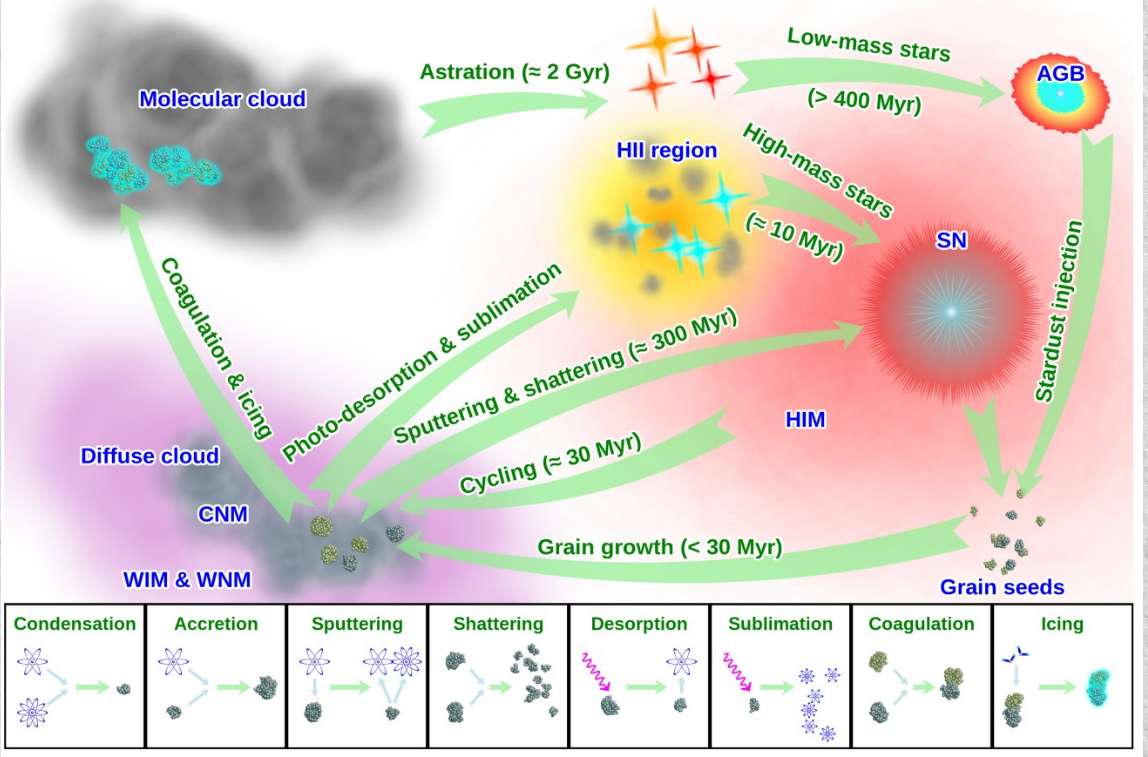


- What is Interstellar Dust?
- The role of Nearby Galaxies.
- NIKA2 maps, ancillary data and image homogenization.
- Modelling dust evolution.
- Preliminary results.
- Summary.

Introduction: Interstellar Dust grains

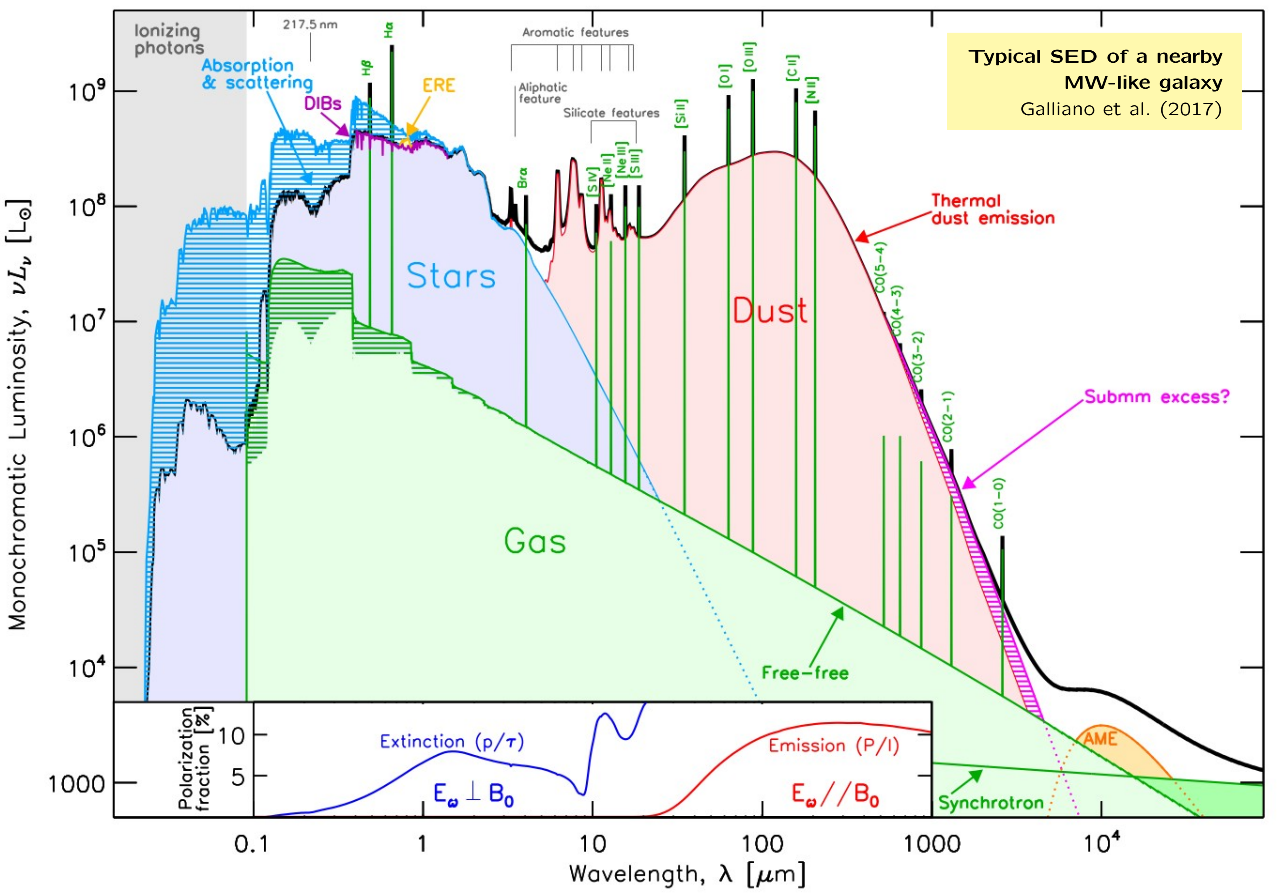


- Sizes range from **10^{-4} to some 10^{-1} µm**.
- In the interstellar medium (ISM), they undergo a variety of processes which **alter** their **size** distribution, **chemical composition** and **abundance**.
- ~ **1%** of ISM mass.



References : Mathis et al. 1977; Galliano et al. 2018; Draine & Hensley 2022

Introduction: Interstellar Dust in galaxies



- Dust grains absorb and reradiate ~**30% of stellar power in the IR** (through scattering, absorption, extinction).
- Dust mass is dominated by **large grains**, responsible for the **thermal emission in the FIR**.
- **Small grains** out of thermal equilibrium are responsible for the **MIR features** (aromatic and aliphatic carbon features and silicate features).
- In the mm regime, the **submm excess** and the **AME** are thought to be linked with the presence of **very cold dust** and **spinning dust grains** (respectively; Galliano+18, Ysard+22).

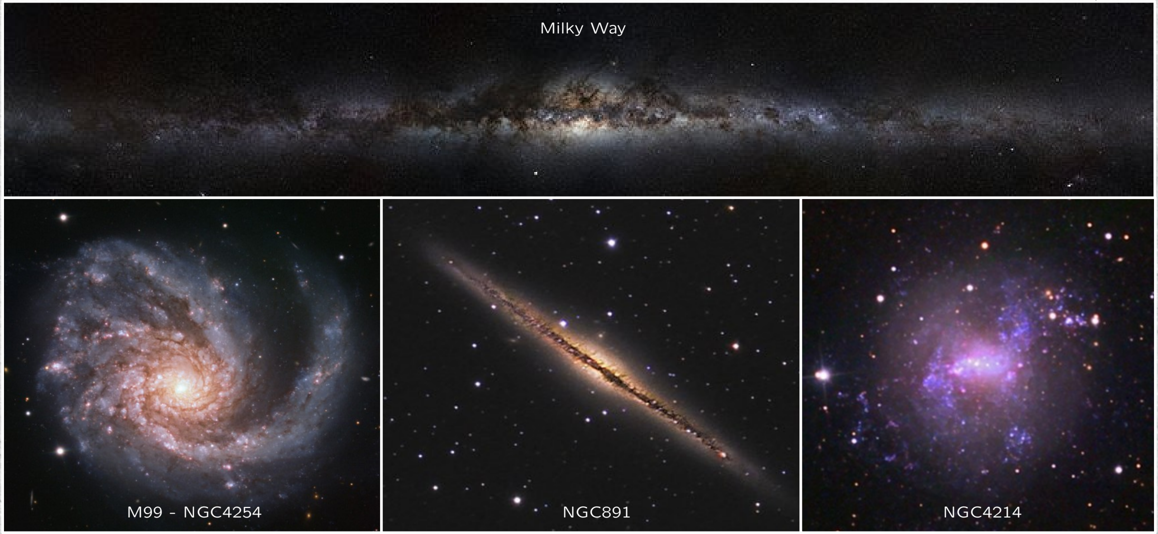
Introduction: why Nearby Galaxies?

Most of our knowledge of ISD properties comes from studies of the **Milky Way**.
(Draine 2003[a], Galliano, Galametz & Jones 2018)

MW hosts a **small range** of environmental conditions:

- Confusion along the sightline.
- No extremely luminous star forming regions (like 30 Doradus in LMC).
- Narrow radial metallicity gradient.
- Passive SMBH.

credits : ESO; NASA/ESA



Nearby galaxies (< 100 Mpc) provide **unique constraints** on ISD properties.

- Faced-on galaxies → **clearer sightlines**.
- Edge-on galaxies → **high vertical distances**.
- Blue Dwarfs ; bright AGNs ; low Z objects
  → probe ISD in **extreme conditions**.
- Intermediate step towards understanding ISD and ISM in **distant galaxies**.

IMEGIN Large Program: main objectives

NIKA2 (IRAM 30m) Guaranteed Time Large Program for Interpreting the Millimetre Emission of Galaxies (PI: S. Madden)

NIKA2 (IRAM 30m) observes at **1.15** and **2 mm**, with angular resolution of **12''** and **18''**. It allows us to:

- sample galaxy SED in the mm range (between SPIRE 500 and radio VLA);
- study the spatially-resolved properties of galaxy millimetre emission.

Main objectives :

- disentangle ISD, free-free and synchrotron emission in spatially-resolved galaxy SEDs;
- constrain the evolution of the dust-to-gas mass ratio within galaxies;
- study the microscopic properties of dust: constraints on millimetric opacity;
- study the submm excess in galaxies.

Tools:

- ISD SED fitting (performed globally and locally) with HerBIE (Gallinano+18).

NGC891
(Katsioli et al. 2023)

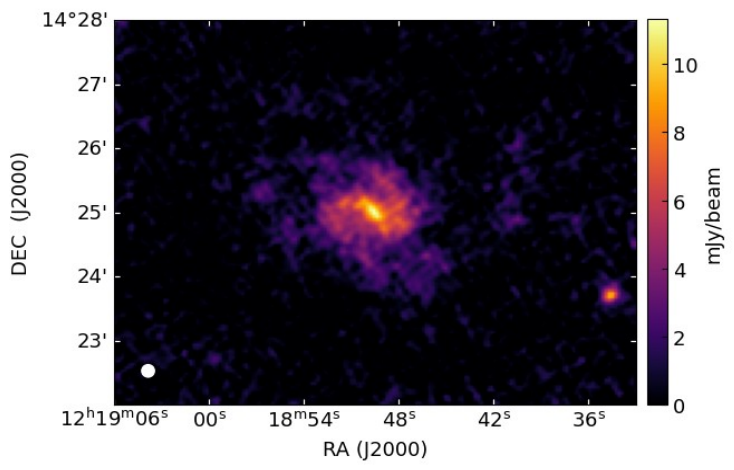
NGC4254
(Pantoni et al. in prep.)

References : Perotto+20, Adam+18, Calvo+16, Bourrion+16

Data: NIKA2 maps (NGC4254)

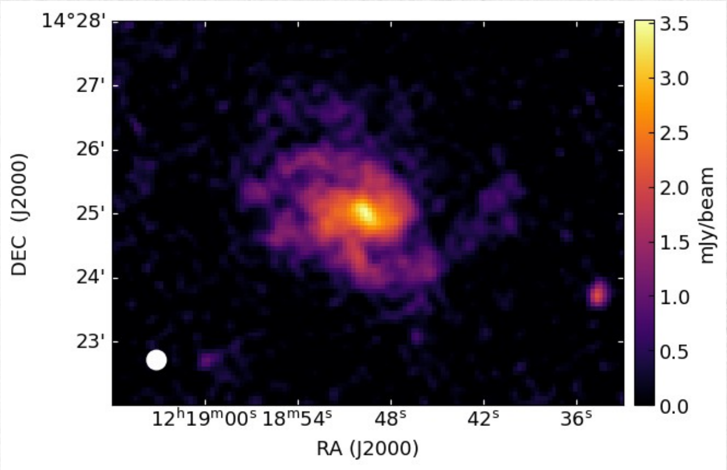
Preliminary NIKA2 maps of NGC4254 (Jan 2023).

NIKA2 data were reduced with **PIIC** (Zylka 2013) by C. Kramer.



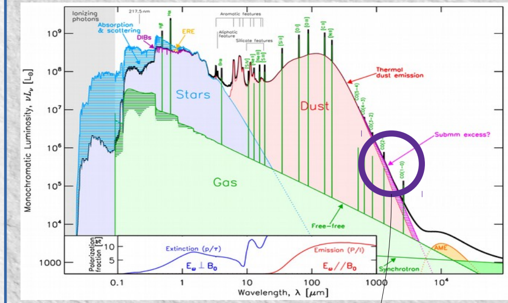
NIKA2 @1.15mm (IRAM 30m)

rms ~ 0.8 mJy/beam



NIKA2 @2mm (IRAM 30m)

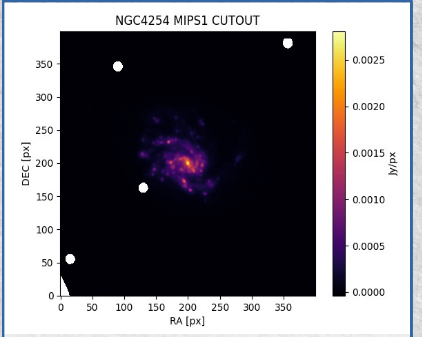
rms ~ 0.24 mJy/beam



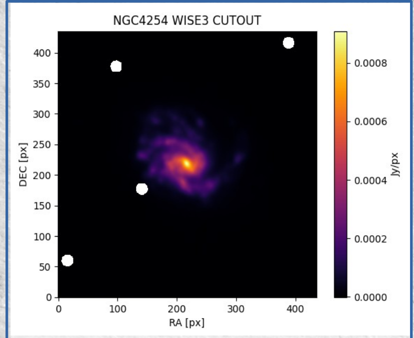
Pantoni et al. in prep.

Data: ancillary maps (NGC4254)

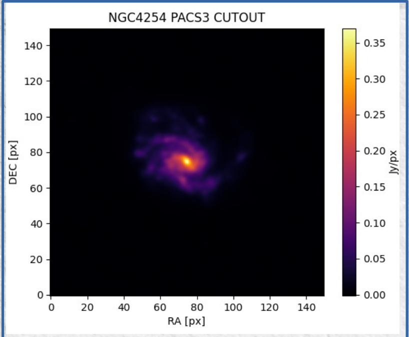
DustPedia archive provides access to multi-λ imagery and photometry for 875 nearby galaxies.
We take advantage of this archive for collecting **NGC4254's IR maps** (for ISD SED fitting).



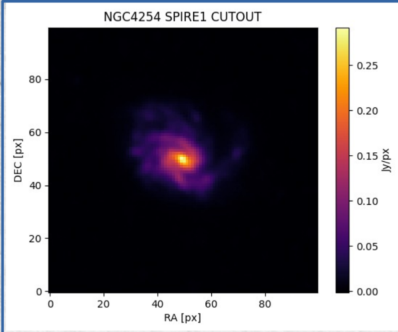
- **Spitzer IRAC 3.6, 4.5, 5.8, 8** (μm)
  θ_{res} [arcsec] ~ 1-2
- **Spitzer MIPS 24** (μm)
  θ_{res} [arcsec] ~ 6



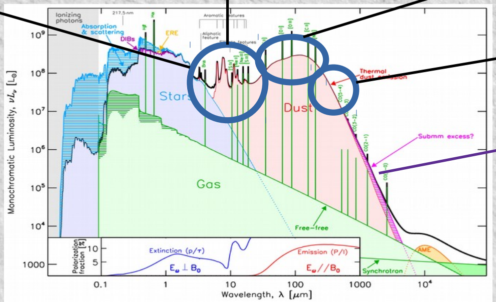
- **WISE 3.4, 4.6, 12, 22** (μm)
  θ_{res} [arcsec] ~ 6-12

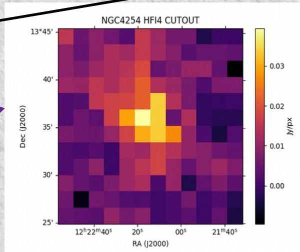


- **Herschel PACS 70, 100, 160** (μm)
  θ_{res} [arcsec] ~ 5-11



- **Herschel SPIRE 250, 350, 500** (μm)
  θ_{res} [arcsec] ~ 18-36

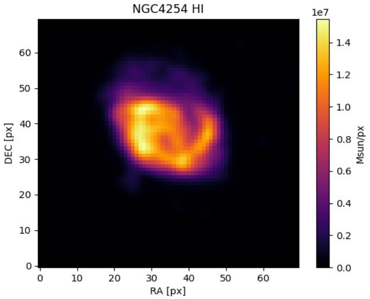




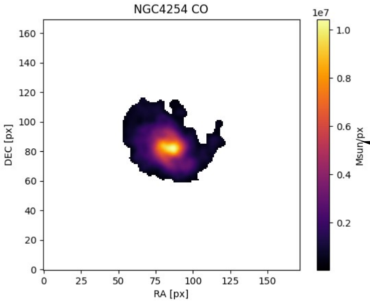
Planck 350, 550, 850, 1380 (μm)
θ_{res} [arcmin] ~ 5
Due to the scarce angular resolution, we use Planck maps only for the global SED and inter-calibration (SPIRE, NIKA2).

DustPedia
http://dustpedia.astro.noa.gr/

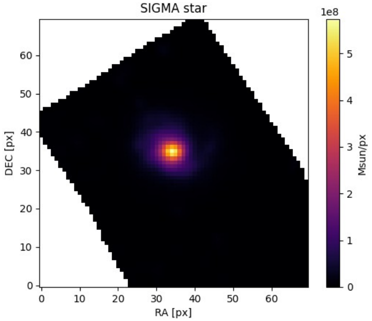
Data: ancillary maps (NGC4254)



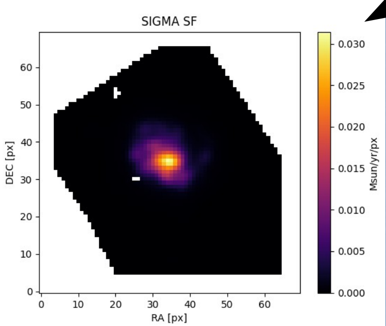
HI VIVA-VLA
θ_{res} [arcsec] ~ 30
(Chung+09)



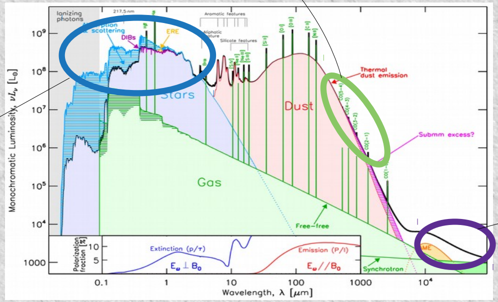
CO(1-0) EMPIRE-IRAM 30m
θ_{res} [arcsec] ~ 27
(Jiménez-Donaire+19)

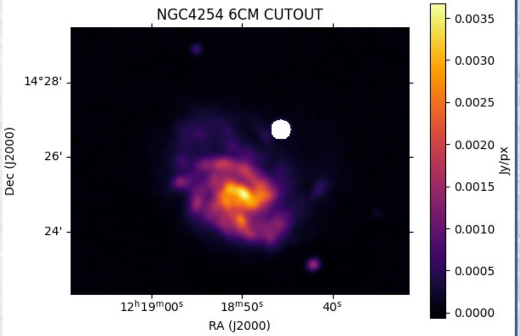


Stellar mass density
(using calib. by Leroy+09)



SFR density
(using calib. by Leroy+09)





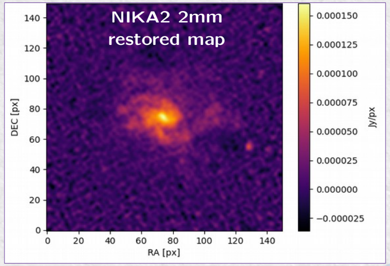
Radio maps at **3, 6 cm**
VLA + Effelsberg; θ_{res} [arcsec] ~ 15
(Chyzy et al. 2007)

Free-free and synchrotron fitting.

- **CO**(1-0), (2-1), (3-2) and **HI** maps → **gas phase** local conditions and **mass**;
- GALEX + IRAC1 and MIPS1 maps → **stellar mass** and **SFR** maps (calibrations by Leroy+08).

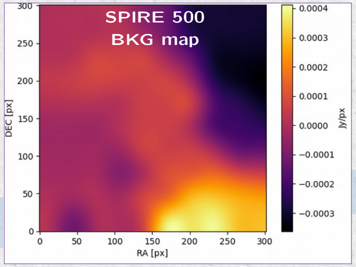
Data homogenization (NGC4254)

The multi-λ maps have **different size**, **spatial resolution**, **pixel size**, **orientation**, **units**.
In order to perform the pixel-by-pixel SED fitting, we need to **homogenize these quantities**.



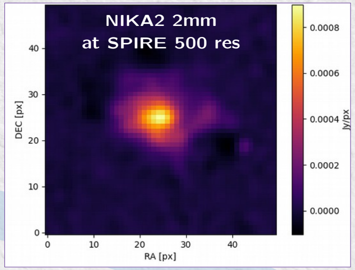
0) - **Large-scale filtered-out flux** in NIKA2 maps is **restored**;
- **CO(2-1) is subtracted** from NIKA2 1.15 mm map.

(Drabek et al. 2012)



1) **Background and foreground** are **modelled** and **subtracted.**

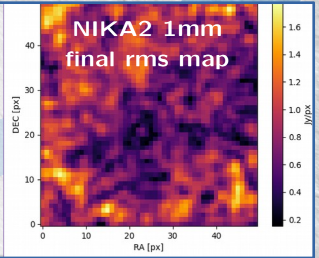
(Cutri et al. 2003)



2) **Maps** are **convolved** to the **same resolution, pixel size** and **orientation.**

(Aniano et al. 2011)

3) **Uncertainties are propagated using the Monte Carlo method.**



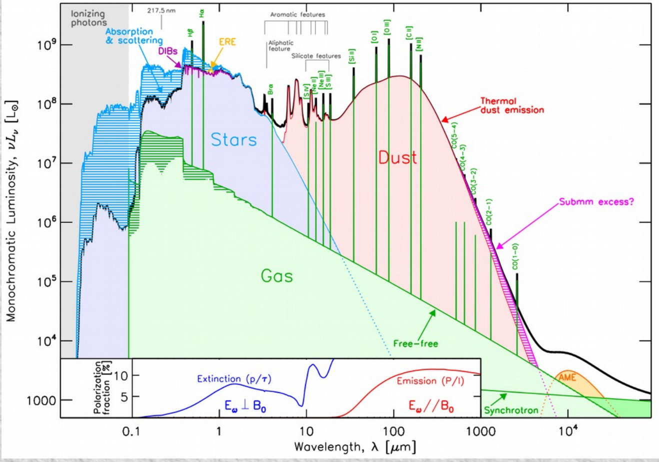
These steps are implemented in the **Homogenization of IMEGIN Photometry** post-processing pipeline (**HIP**; **Pantoni et al. in prep.**)

Methods: dust SED fitting and modelling

We use **HerBIE** **(Galliano 2018)** to fit the dust SED of IMEGIN galaxies.

HerBIE is a hierarchical bayesian SED fitting code which:

- allows for the use of a **non-uniformly illuminated dust mixture** (free parameters : $\mathbf{M_{dust}}$, $\mathbf{U_{min}}$, $\mathbf{q_{AF}}$);
- includes **Near-IR** emission by **stellar populations** (BB of given T);
- includes **free–free** and **synchrotron** continua (radio).



HerBIE returns the **pdf,** the **map of dust parameters** and **their uncertainties** (noise and calibration).

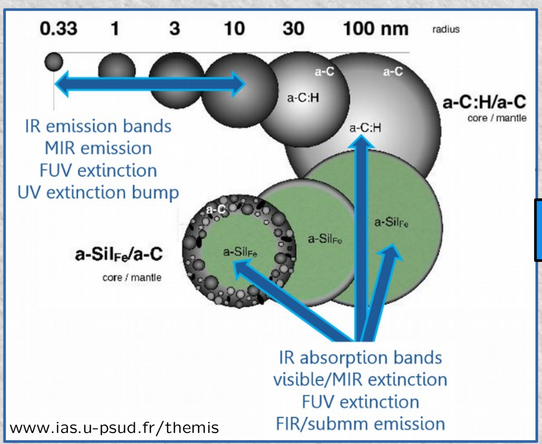
HerBIE incorporates the state-of-the-art dust model **THEMIS** **(Jones et al. 2017)**.

It provides HerBIE with **realistic ISD grains optical properties**.

Methods: dust SED fitting and modelling

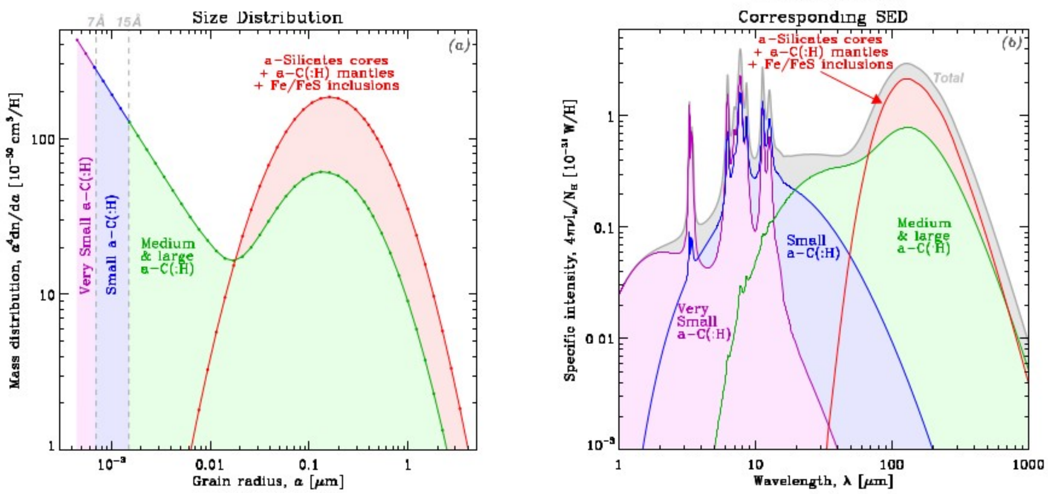
THEMIS (The Heterogeneous dust Evolution Model for Interstellar Solids; **Jones et al. 2017**):

- consists of **core-mantle carbon and silicate grains**;
- is anchored **to the laboratory-measured optical properties** (e.g., Q_{ex}, n) of ISD analogues (i.e. amorphous hydrocarbons and amorphous silicates);

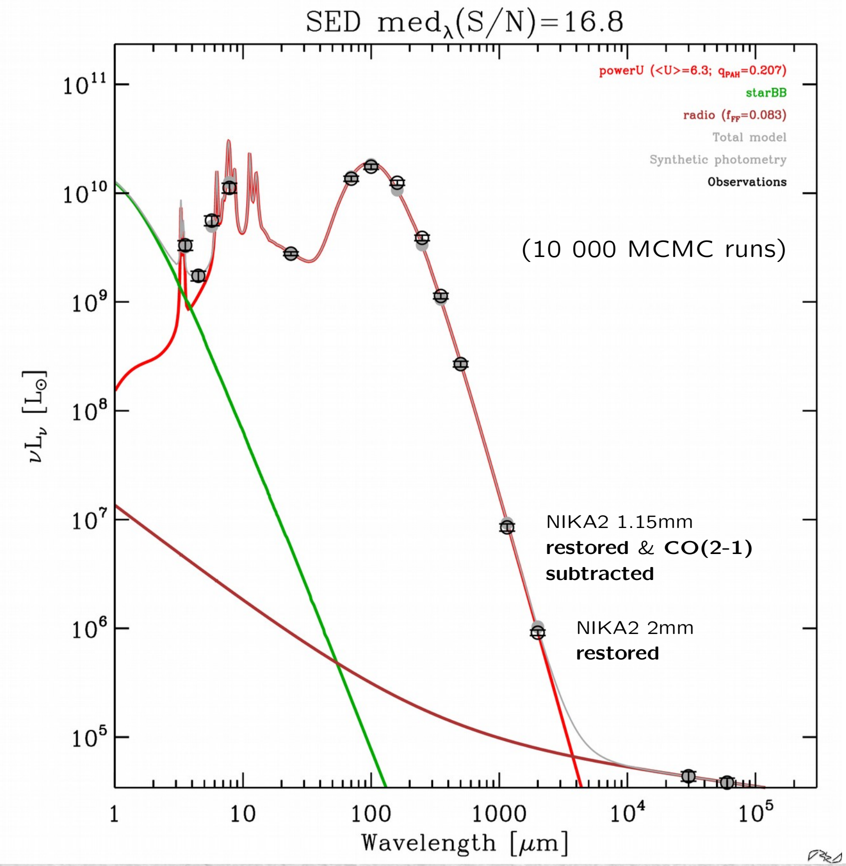


Galliano et al. 2021

Fig. 1. *Parametrization of the THEMIS model.* Panel *(a)* shows the size distribution of the two main components of THEMIS: amorphous carbons and silicates. We show how we divide the a-C(:H) size distribution into three independent components. Panel *(b)* shows the SED corresponding to each component (same color code as panel *a*). The SED is shown for the ISRF of the solar neighborhood (Mathis et al. 1983).

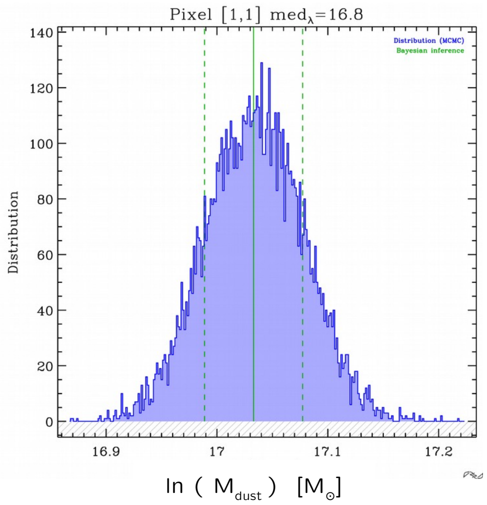


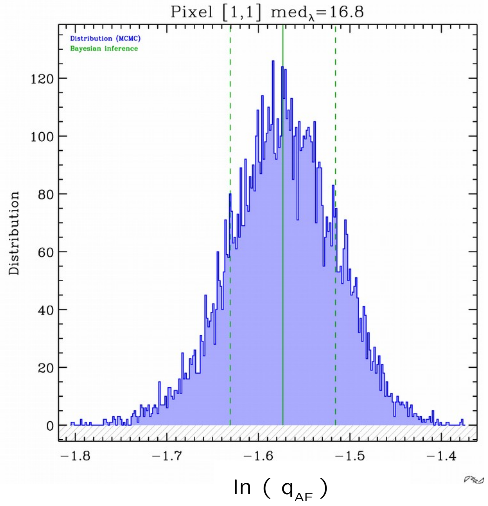
Preliminary results: integrated SED (NGC4254)



Global photometry is computed on the same DustPedia ellipse; values were checked against literature.

The **SED fitting with Herbie** (Galliano+18) gives the probability distribution function of free parameters, e.g. :





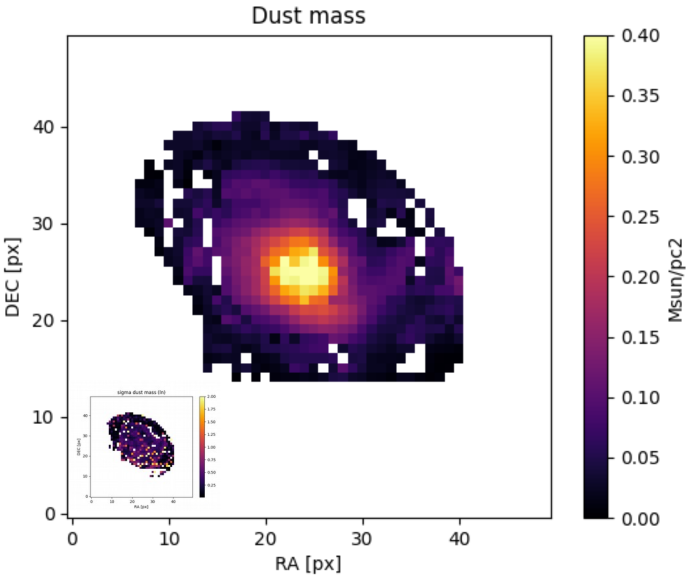
$M_{dust} = (2.5\pm0.1)\times10^7\ M_\odot$

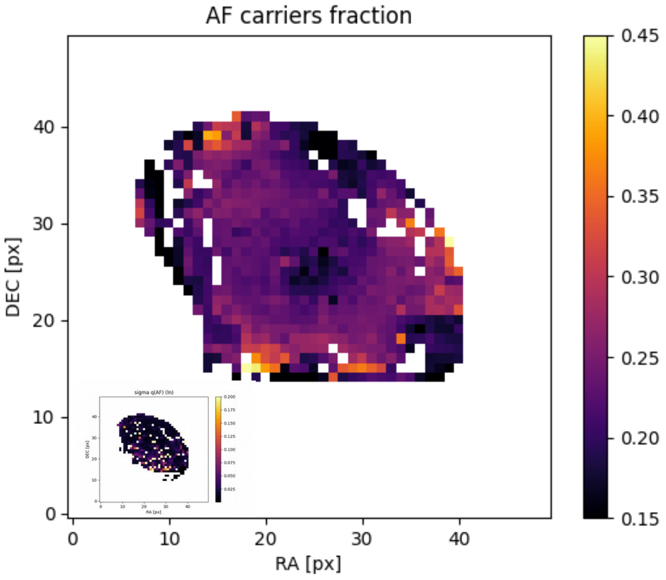
$q_{AF} = 0.2\pm0.01$

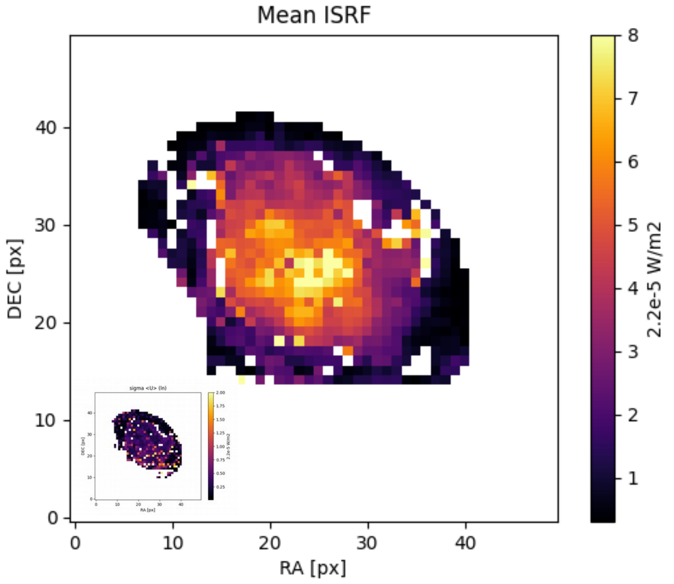
Pantoni et al. in prep.

Preliminary results: spatially resolved analysis

Pixel-by-pixel SED fit of **NGC4254** (**with HerBIE**, ~1e8 runs; gas/stellar mass and SF maps set as priors) allows us to study the spatial distribution of the main parameters characterizing ISD emission in the galaxy.



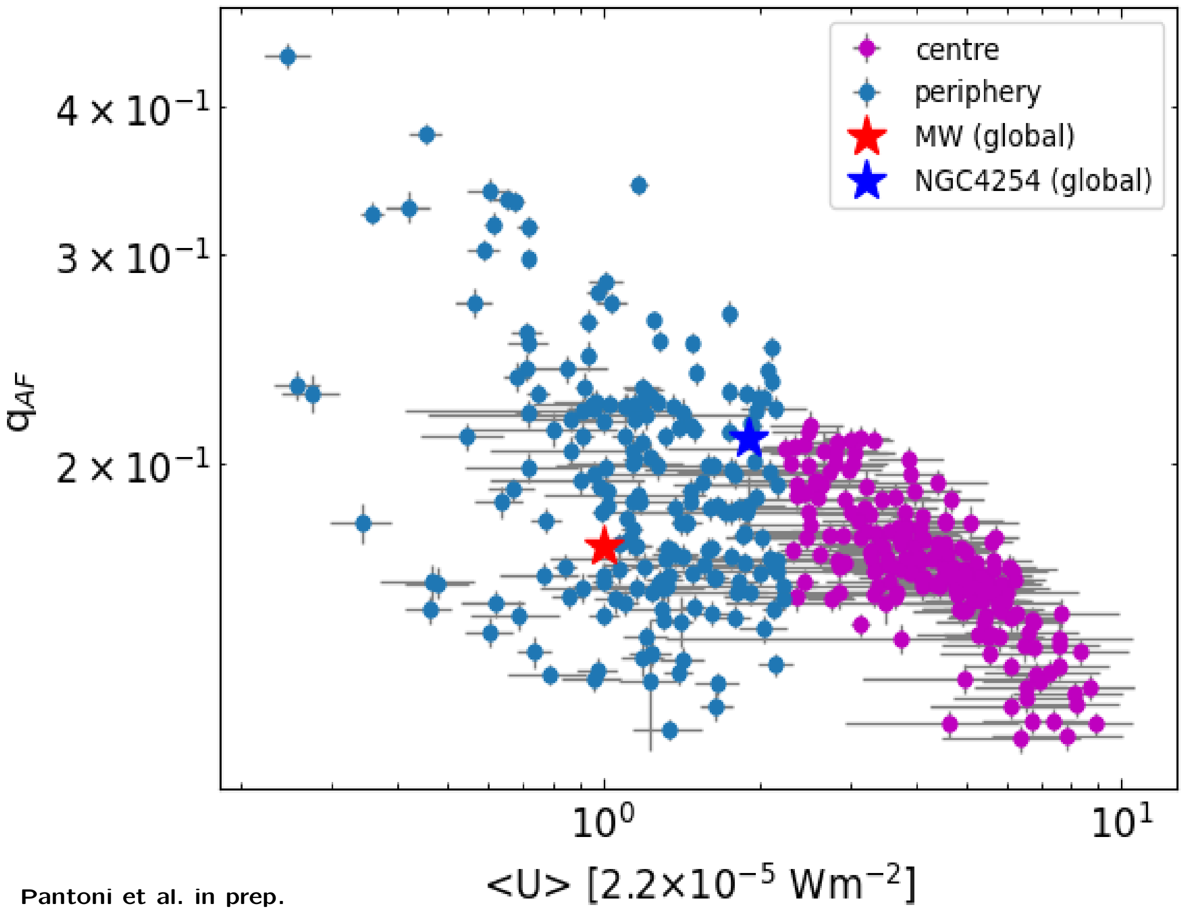




- Dust mass (dominated by large grains) is mostly located in the central part of the NGC4254.
- Small grains carrying aromatic features (i.e., the fraction of is q_{AF}) are located preferentially in the periphery of NGC4254.
- The averaged interstellar radiation field (ISRF), i.e. $<U>$, peaks in the center of M99 and progressively decreases towards the periphery.

Pantoni et al. in prep.

Preliminary results: spatially resolved analysis

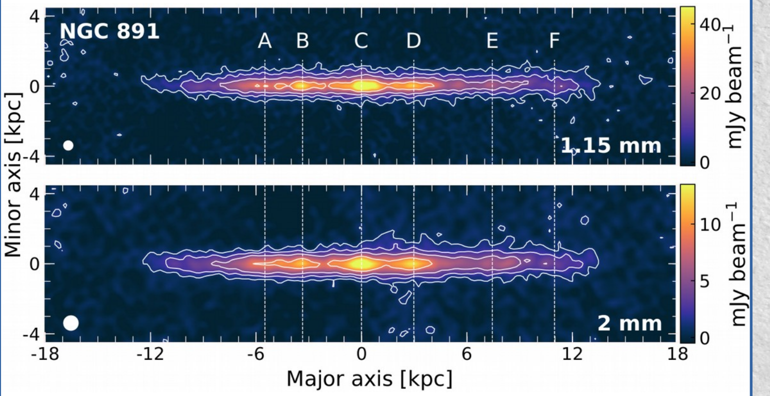


Pantoni et al. in prep.

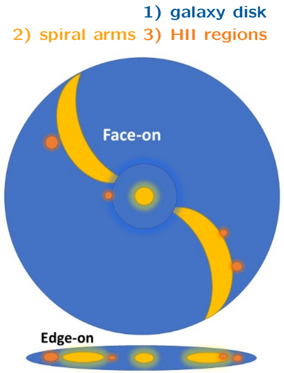
- It results in an **anti-correlation** between aromatic features carriers and the strength of the interstellar radiation field.
- In hard radiation field conditions, **small dust grains are very efficiently depleted**.
- The anti-correlation is also observed in other nearby galaxies / SF regions (e.g., M83, M82, M51, M17, 30 Dor, Orion bar).
- **Flattening** towards **lower <U>** and galaxy **periphery**:
  1) driven by a metallicity gradient? (see Boselli et al. 2021)
  2) issues in modelling the diffuse emission in the outskirts?

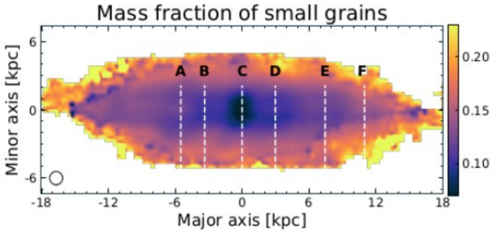
NGC891: the stratification of ISM properties

S. Katsioli et al. 2023



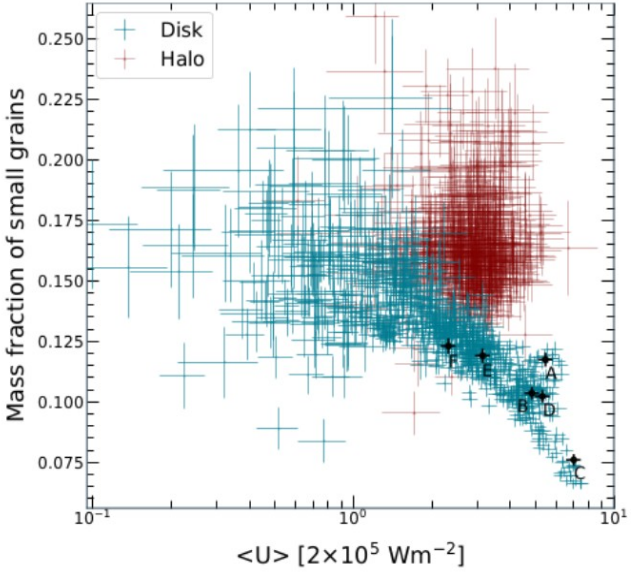
- **NIKA2 maps** at 1.15 mm and 2 mm.
- We perform the **spatially-resolved SED fitting** analysis from IR to radio bands, using HerBIE (Galliano+18).





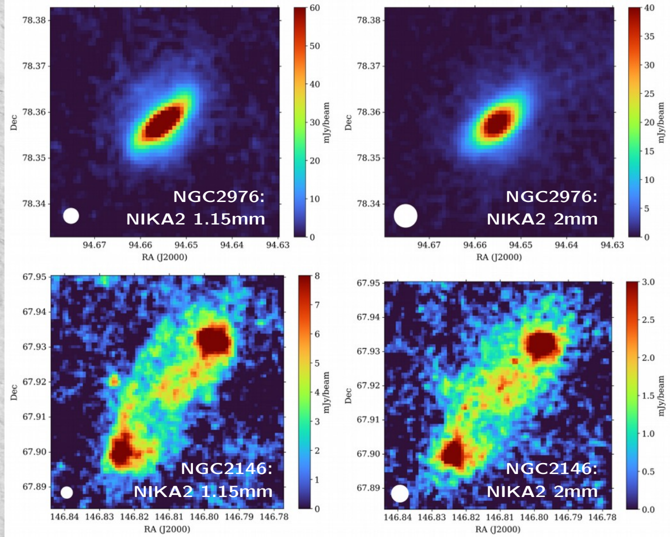
- Region A: the ehnanchement might be due to **grains sheilded in the molecular cocoon** of giant HII region.
- Disk: small grains are **destroyed** in strong radiation field conditions (**UV photons**; e.g. Draine+07, Rémy-Ruyer+15, Galliano+21).
- Halo: ehnanchement might due to **shattering** of larger carbon grains **in the outflows**.

There is a clear **anti-correlation** between **small dust grains** and the **ISRF**.



NGC2976 and NGC2146: T_{dust} and SFR

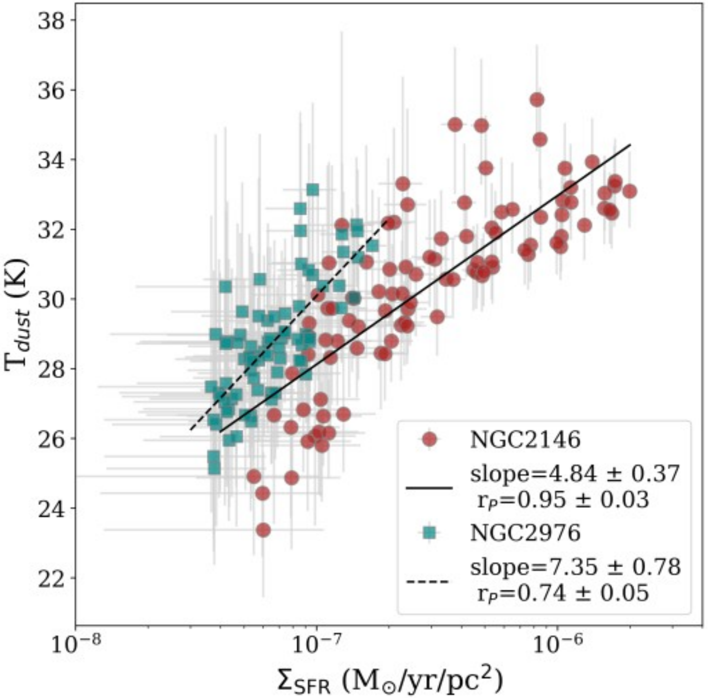
G. Ejlali et al. in prep



- **NIKA2 maps** at 1.15 mm and 2 mm.
- Dust thermal emission modelled with a modified-BB; free-free and syncrotron with two power laws; SFR surface density from 24µm map (Calzetti+07).
- We perform the **spatially-resolved dust SED fitting** using the MCMC method via python package *emcee.*

SED parameter	NGC2146	NGC2976
T (K)	29.61 ± 2.78	27.68 ± 1.86
M ($M_\odot$)	$(2.65 \pm 2.33) \times 10^5$	$(2.00 \pm 0.75) \times 10^3$
β	1.90 ± 0.11	1.38 ± 0.13
f_{th}	$(8.82 \pm 6.92) \times 10^{-2}$	$(3.90 \pm 2.93) \times 10^{-1}$

Mean value of free parameters in pixel-by-pixel SED modelling, with their standard deviation.



Higher SFR → stronger ISRF → dust heating.

- T increases faster in NGC2976 than in NGC2146 (x2).

NGC2976 (dwarf)

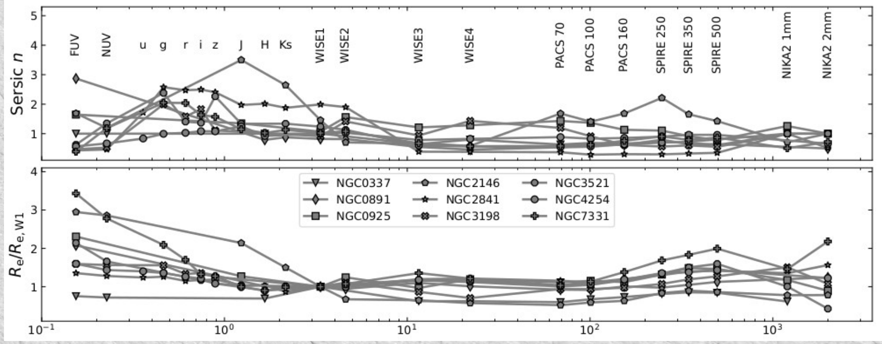
Low metallicity and dust opacity: stellar radiation can penetrate more the thinner ISM, giving a faster dust grains heating rate.

NGC2146 (starburts)

More efficient shielding (thicker ISM) of dust grains from energetic stellar radiation, which implies a slower heating rate.

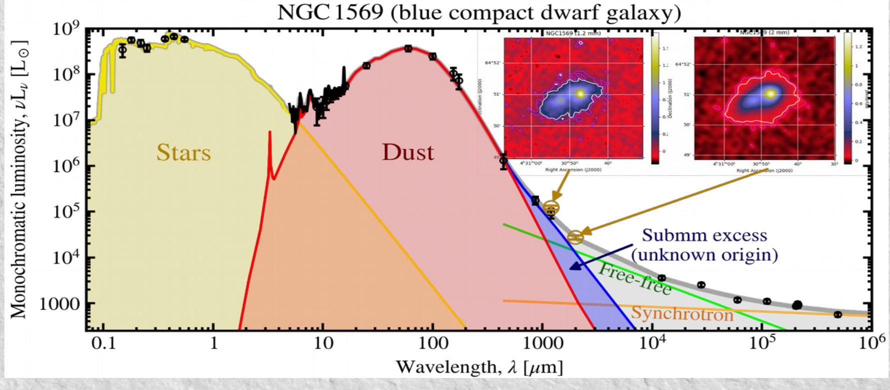
Ongoing projects and perspectives

- A. Nersesian et al. (in prep.): **millimetre morphology of IMEGIN galaxies**.



Nersesian et al. in prep.

- Further in-depth with NIKA2 on **dwarf galaxies** (**NGC1569**, **NGC4214**, **NGC4449**) thanks to the ongoing project **SEINFELD** (*Sub-millimeter Excess In Nearby Fairly-Extended Low-metallicity Dwarfs*; PI: Galliano) for constraining the millimeter emission of low metallicity objects.



credits: F. Galliano

Summary

1 ***NIKA2*** millimeter maps
(IMEGIN ; PI : Madden)
\+
DustPedia multi-wavelength data
(optical/near-IR-to-cm)

→ Spatially-resolved observed SEDs ;

2 ***THEMIS*** dust grains evolution model (Jones et al. 2017)
→ ***HerBIE*** hierarchical Bayesian SED fitting code (Galliano 2018)

→ Maps of dust parameters ;

3 Constrain ISD properties in ≠ environments

→ Constrain dust evolution processes.

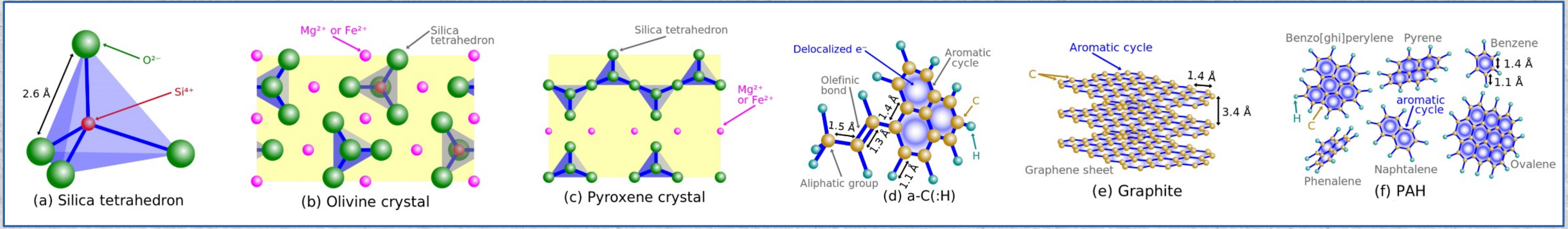
ACKNOWLEDGEMENTS

S. Madden, **F. Galliano**, **A. Jones**, **N. Ysard**, J. Tedros, A. Nersesian, H. Roussel, C. Kramer, G. Ejlali, S. Katsioli, X. Desert, M. Smith, M. Xilouris, A. Hughes and NIKA2 collaboration.

Backup slides

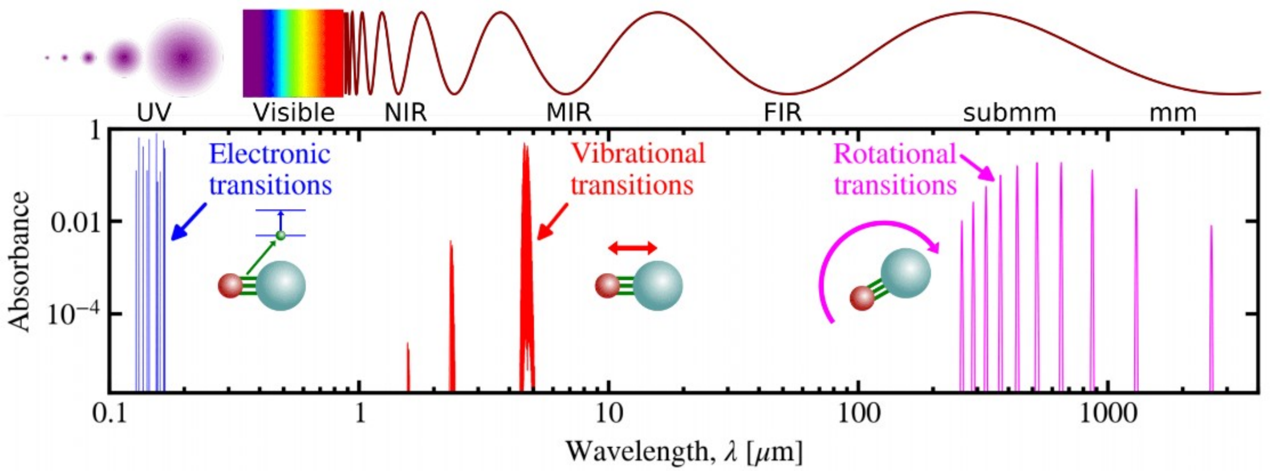
Introduction: dust candidates

Credits : F. Galliano

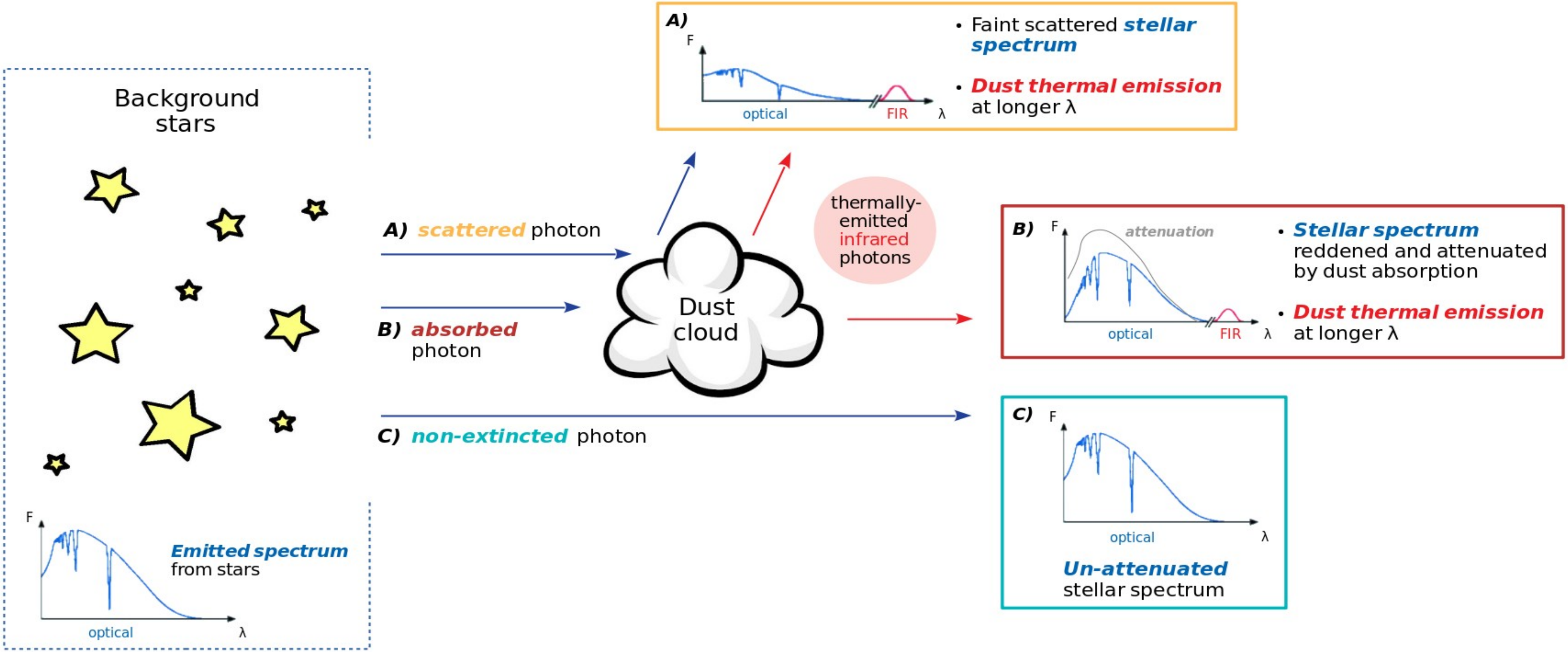


Dust grains show their nature by interacting with light.

The most relevant transitions are in the ***MIR*** and associated with the ***stretching or bending of a bond***.



Introduction: dust extinction

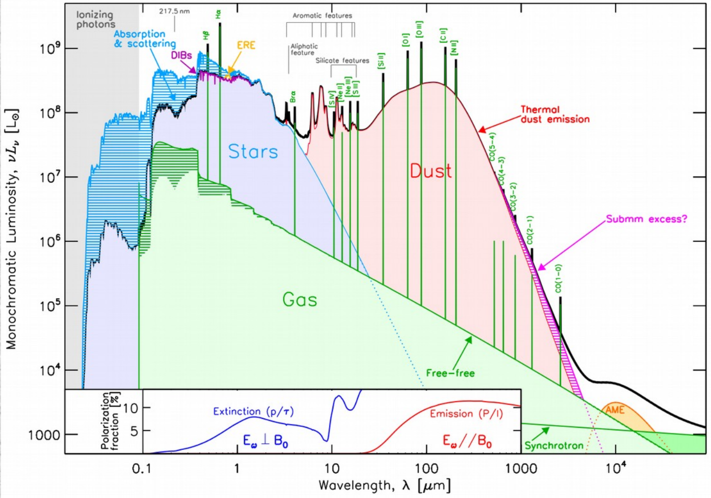


Methods: dust SED fitting and modelling

We use **HerBIE (Galliano 2018)** to fit the dust SED of IMEGIN galaxies.

HerBIE is a hierarchical bayesian SED fitting code (MCMC with Gibbs sampling) which:

- allows for the use of a **non-uniformly illuminated dust mixture** parameters : $\mathbf{M_{dust}}$, $\mathbf{U_{min}}$, $\mathbf{q_{AF}}$);
- includes **Near-IR** emission by **stellar populations** (BB of given T);
- includes **free–free** and **synchrotron** continua (radio).



HerBIE returns the **pdf,** the **map of dust parameters** and **their uncertainties** (noise and calibration).

- The posterior pdf is the product of a classical likelihood and a prior pdf.
- The prior depends on the **hyperparameters**: the average of each physical parameter; the covariance matrix (we are sampling a single, large dimension, joint pdf).

HerBIE is effective in: 1) modelling poorly-constrained SEDs (with upper limits or missing fluxes);
2) suppressing the noise-induced, false correlations between parameters (e.g. least squares or non-hierarchical).

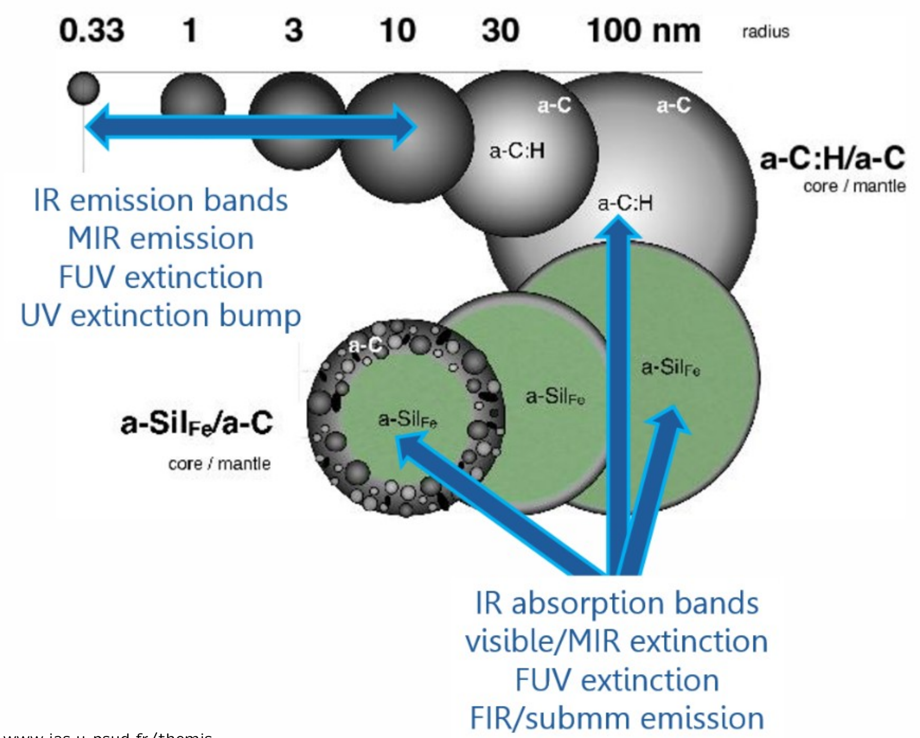
Methods: THEMIS

HerBIE incorporates the dust properties of The Heterogeneous dust Evolution Model for Interstellar Solids; **Jones et al. 2017**

- THEMIS consists of **core-mantle carbon and silicate grains**;
- THEMIS is anchored to the ***laboratory-measured properties*** of inter-stellar dust analogues.

↓

Optical properties
(e.g., refraction index).

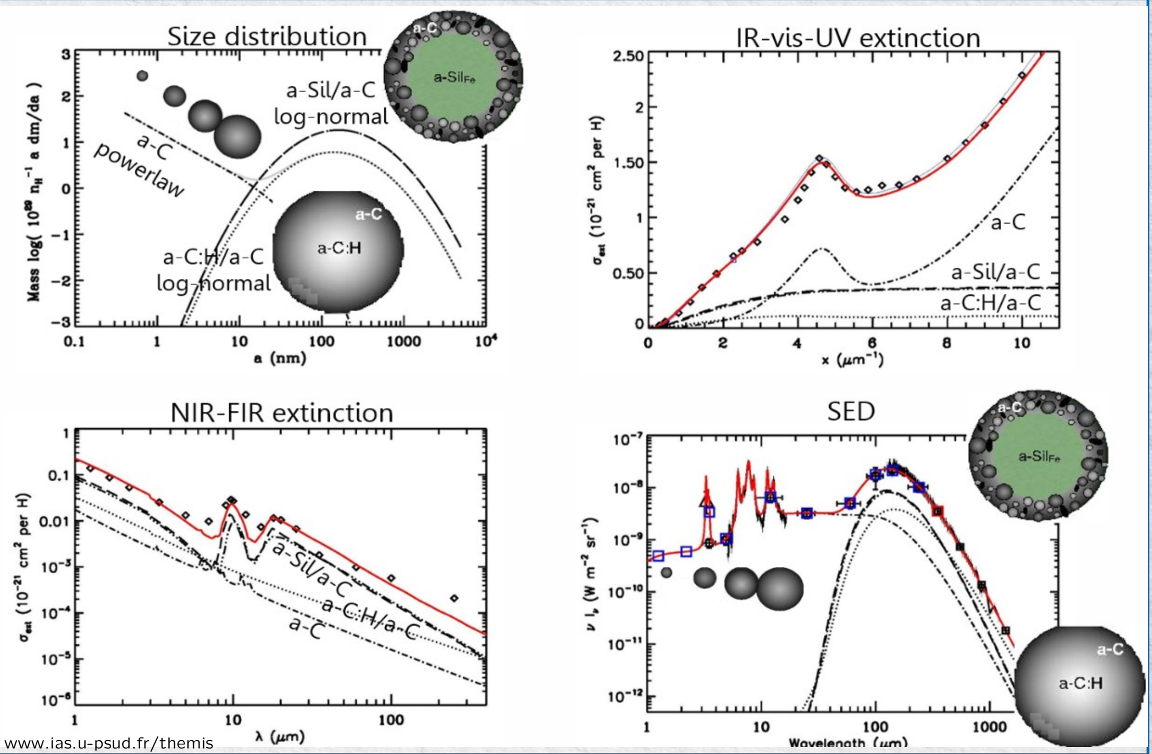


www.ias.u-psud.fr/themis

Methods: THEMIS

Interstellar dust size distribution, chemical composition and structure react to and adjust to :

- **local radiation field** intensity and hardness ;
- **gas density and dynamics** (diffuse ISM, molecular clouds).

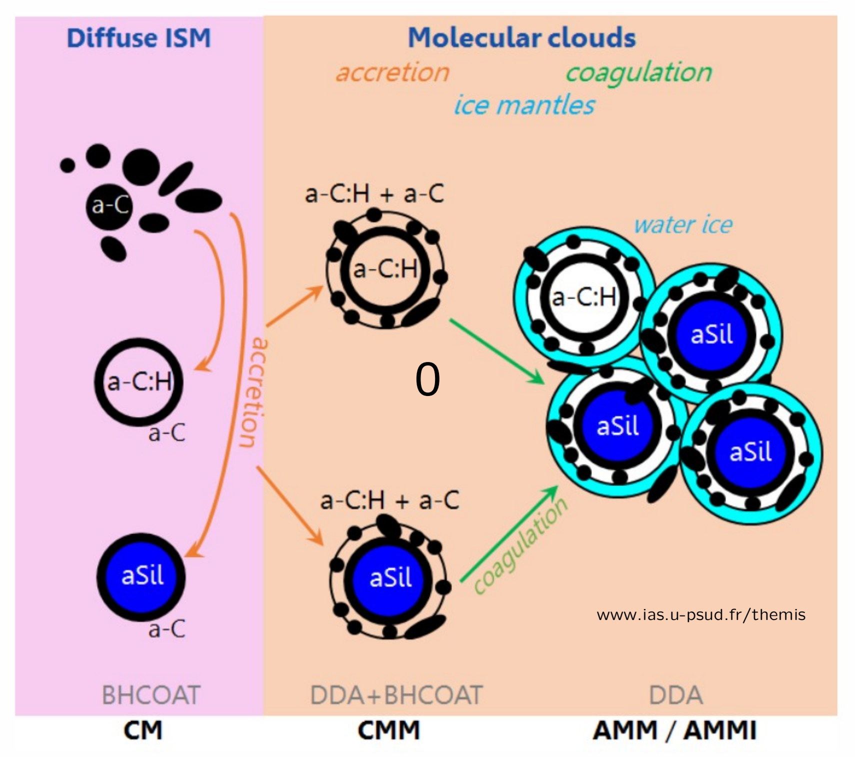


Methods: THEMIS

Interstellar dust is heterogeneous, as a result of :

- grain surface **photo-processing** ;

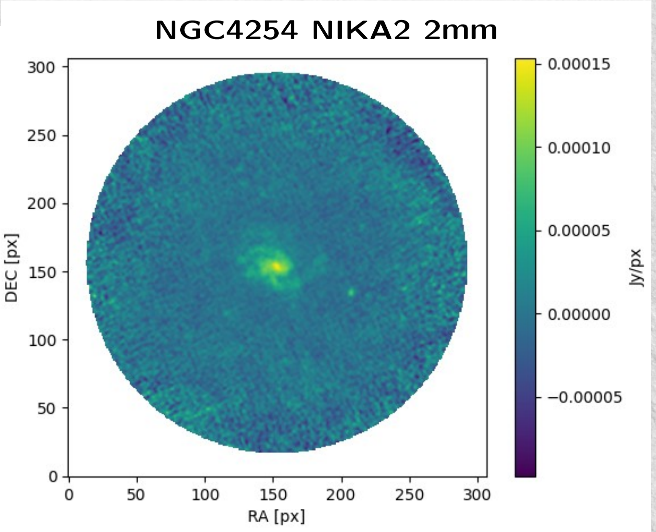
- **mantle accretion** and **coagulation**.



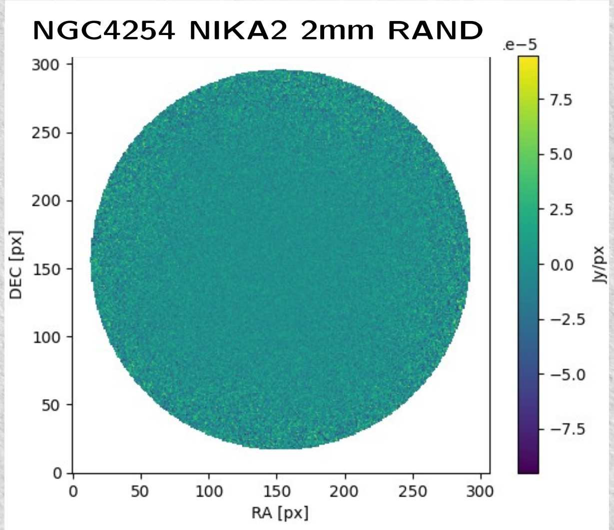
HIP: Monte Carlo for uncertainty propagation

Monte Carlo method (frequentist approach) relies on **random perturbations** that are **added to the data** map for a **number N of iterations**. It accounts for e.g. correlations between pixels.

1) The random perturbation is a random normal distribution centered on zero with standard deviation equal to the original uncertainty (PIIC pipeline) on the data map.



DATA



RANDOM PERTURBATION

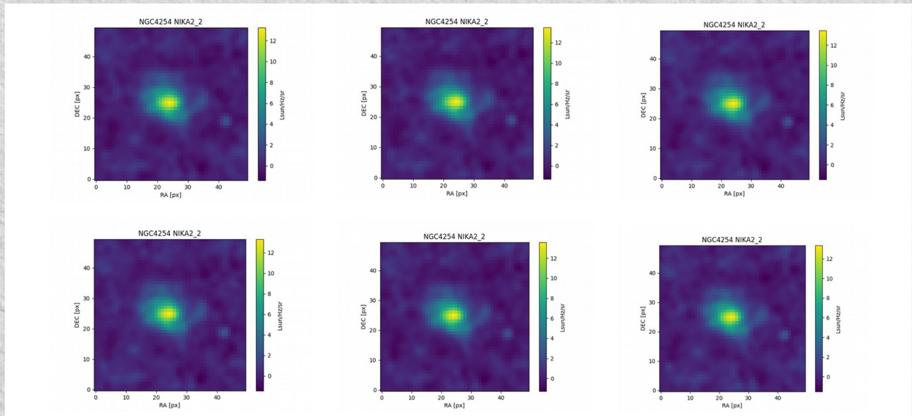
Do it **N times** and **iterate through data processing...**

Pantoni et al. in prep.

HIP: Monte Carlo for uncertainty propagation

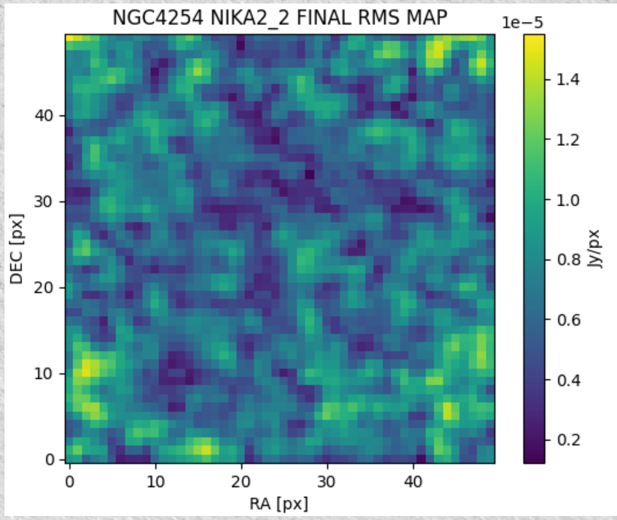
2) After N iterations, we have N perturbed data map that have been processed in the same way.

3) The px-by-px standard deviation of the N data maps gives the **final statistical uncertainty map**.



N random realization of the processed data map

STD



Pantoni et al. in prep.

HIP: restoring the large-scale emission

- Large-scale filtering may occur while observing extended sources with ground-based observatories (such as IRAM 30m) as a side consequence of removing the noise induced by Earth's atmosphere (e.g. Sadavoy+13; Smith+21; Pattle+23).

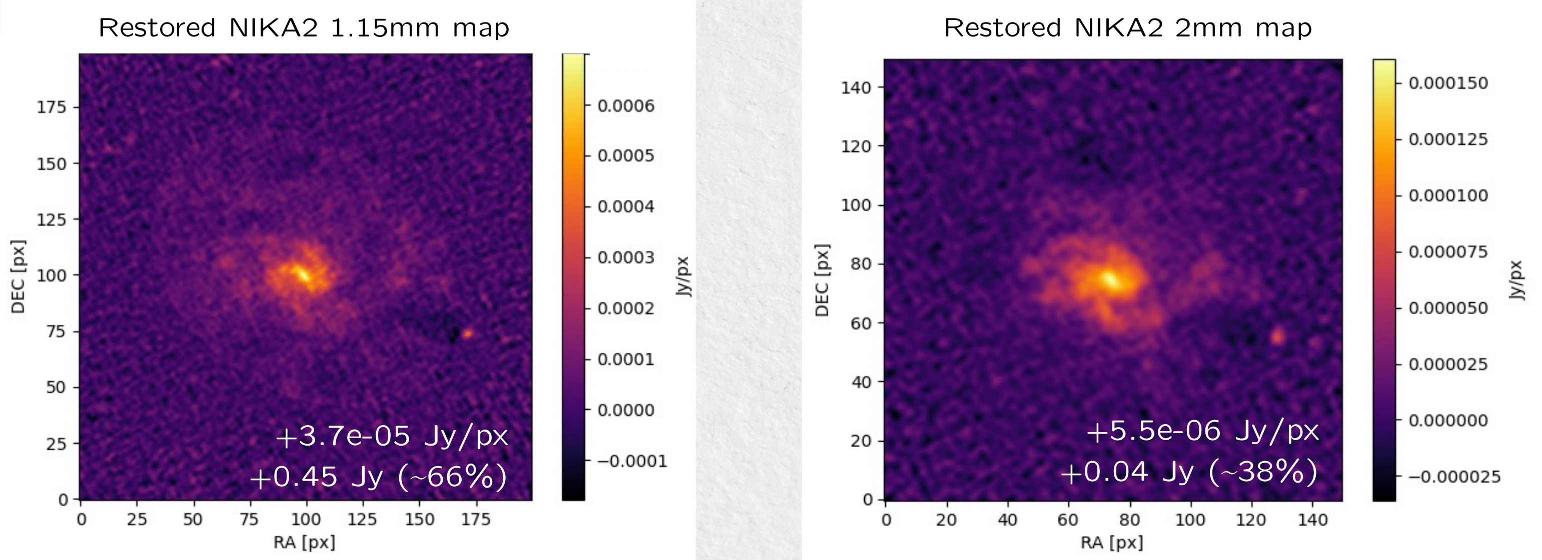
- A possible approach consists in developing some **techniques for restoring the filtered-out flux** taking advantage of **space observatories (e.g. Planck)** observing in the same wavelength range.

- By comparing NGC4254 **NIKA2 1.15mm** global flux and **Planck 1.38 mm** (corrected for filter shape and central wavelength), we find that **more than 60% of the flux is filtered-out**.
- **NIKA2 2mm** loss is $\sim$ 40%.

HIP: restoring the large-scale emission

UNIFORM FLUX REDISTRIBUTION

The basic idea is redistributing uniformly the amount of flux that is filtered out on a global scale, by comparing with Planck HFI4 (1.38 mm).



Pantoni et al. in prep.

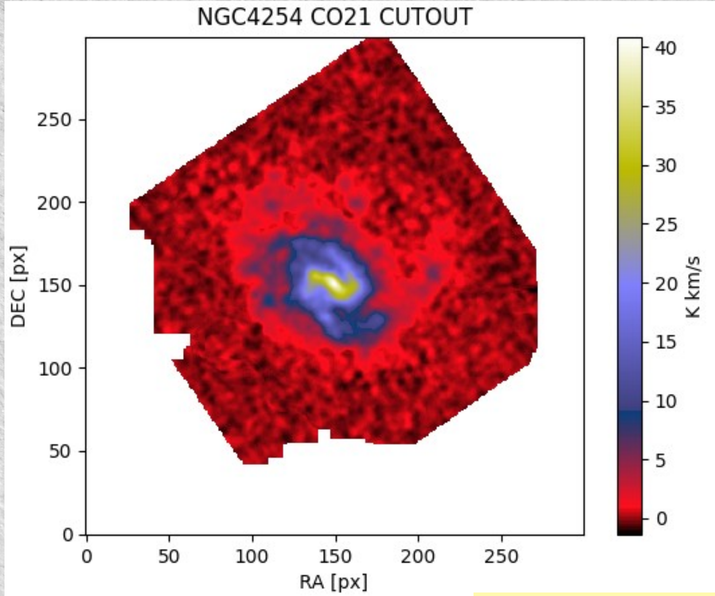
HIP: CO(2-1) subtraction

This step allows us to correct for the CO(2-1) continuum contamination at 1.15 mm (NIKA2). In case of large-scale emission filtering, it is applied on the *restored* NIKA2 map (where the lost flux is added back). Uncertainties are propagated through MC method.

For NGC4254, we use the CO(2-1) map from HERACLES (Leroy+09), and equation (8) in Drabek+12:

$$\frac{C}{\text{mJy beam}^{-1} \text{ per K km s}^{-1}} = \frac{F_\nu}{\int T_{\text{MB}}\, \mathrm{d}v} = \frac{2k\nu^3}{c^3} \frac{g_\nu(\text{line})}{\int g_\nu\, \mathrm{d}v} \Omega_{\text{B}}, \quad (8)$$

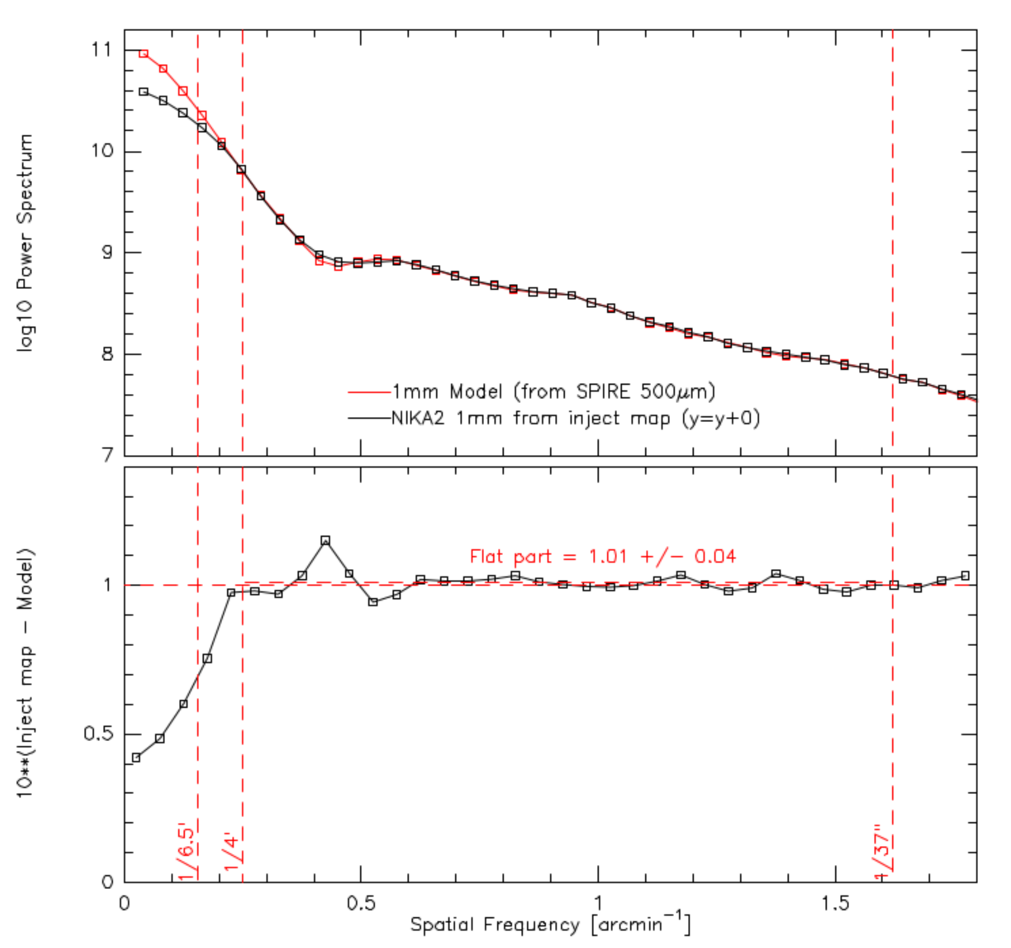
where frequencies are measured in GHz and $1\ \text{Jy} = 10^{26}\ \text{W m}^2\ \text{Hz}^{-1} = 10^{23}\ \text{erg s}^{-1}\ \text{cm}^{-2}\ \text{Hz}^{-1}$.



Pantoni et al. in prep.

The global flux at 1.15mm (NIKA2) corrected for CO(2-1) contamination is ~ 0.63 Jy, against the original ~ 0.69 Jy (restored). CO(2-1) contribution to NIKA2 1mm is ~ **9%**.

Large-scale emission filtering: NGC6946

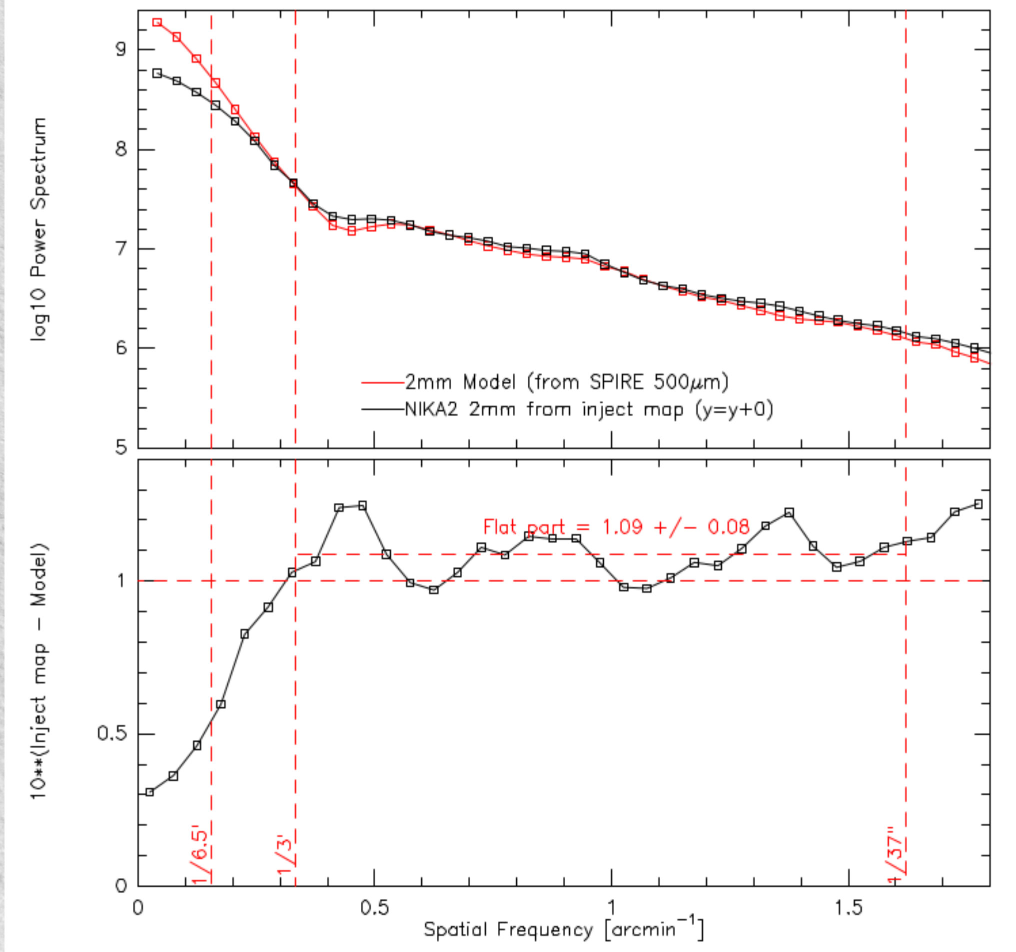


NIKA2 1.15mm radial POWER SPECTRUM (NGC6946 - IMEGIN; by C. Kramer)

NIKA2 1.15mm TRANSFER FUNCTION (NGC6946 - IMEGIN; by C. Kramer)

- At 1.15 mm, the flat part extends till 4.5'.
- At the scale of the NIKA2 field-of-view, the transfer function is reduced to 70%.
- The flat part stays at 1.01 ± 0.04.

Large-scale emission filtering: NGC6946



NIKA2 2mm radial POWER SPECTRUM (NGC6946 - IMEGIN; by C. Kramer)

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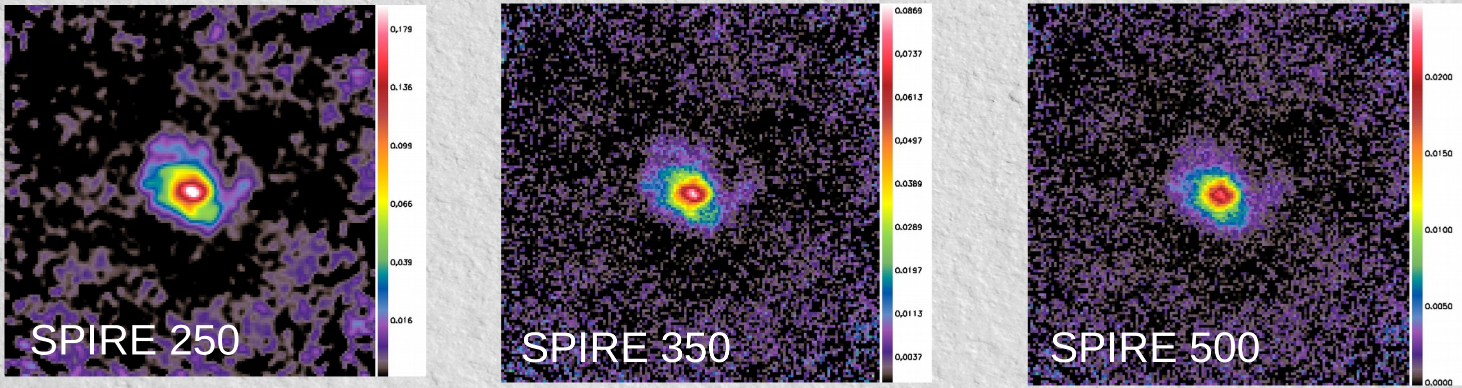
NIKA2 2mm TRANSFER FUNCTION (NGC6946 - IMEGIN; by C. Kramer)

- At 2 mm, the flat part extends till 3'.
- At the scale of the NIKA2 field-of-view, the transfer function is reduced to ~ 50%.
- The flat part stays at 1.09 ± 0.08

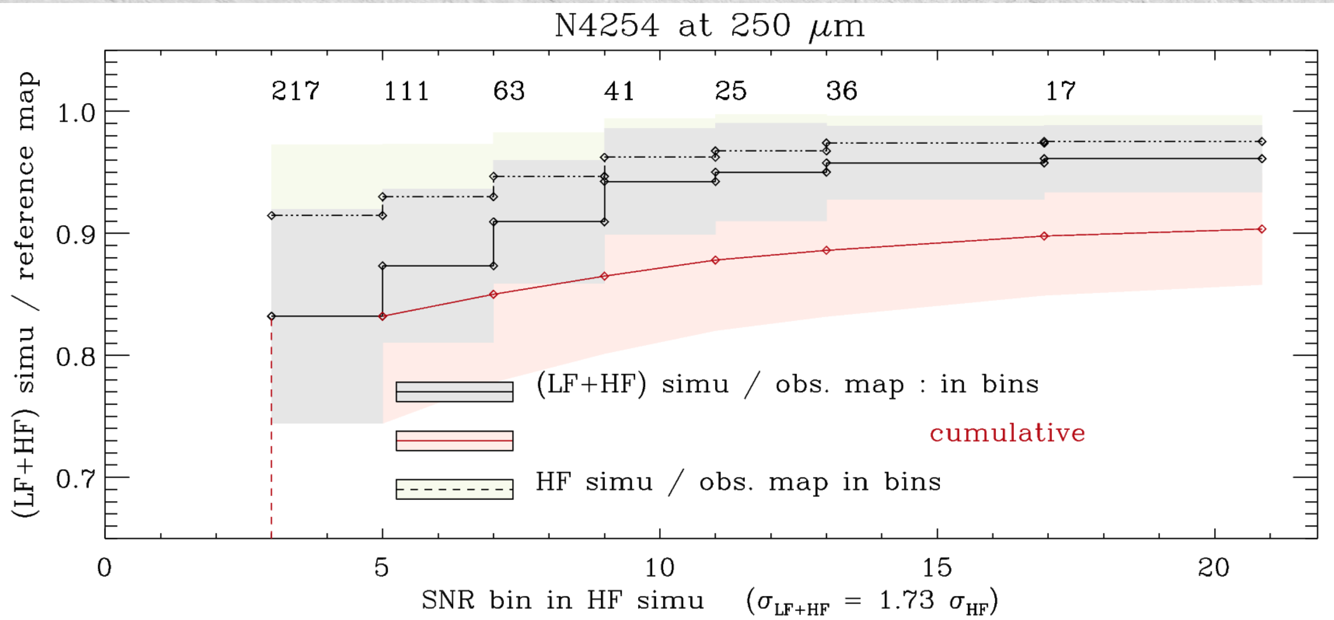
NGC4254: large-scale emission filtering

One possible approach consists in **filtering-out the multi-wavelength ancillary maps as the NIKA2 maps** were filtered-out, adding the ancillary maps to the timeline series (see e.g. Pattle et al. 2023; Sadavoy et al. 2013).

Simulation for Herschel-SPIRE bands (by H. Roussel, to be used in Pantoni et al. in prep):

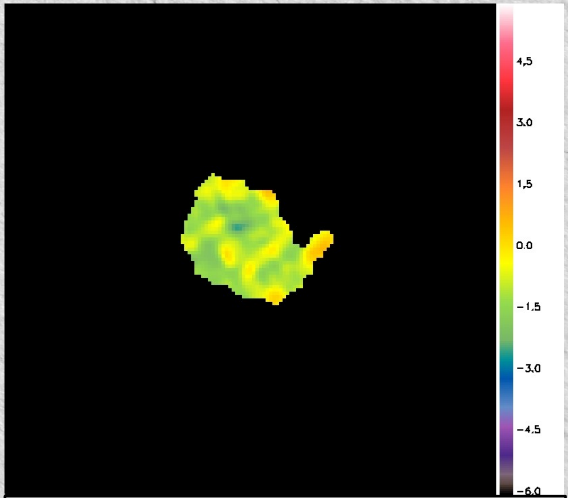


NGC4254: large-scale emission filtering



SPIRE 250 TRANSFER FUNCTION

Courtesy of H. Roussel



SPIRE 250 SIGMA TOT

NGC4254: large-scale emission filtering

An alternative/complementary approach consists in developing some **techniques for restoring the filtered-out flux** taking advantage of **space observatories (e.g. Planck)** observing in the same wavelength range.

I. **FEATHERING** (e.g. Smith et al. 2021)
is a method originally used in radio astronomy for combining interferometric data with single dish.
The method is **suitable for NGC6946** (d ~ 11.5 arcmin; Ejilali et al. in prep.).
Its applicability to the case of NGC4254 (d ~ 5 arcmin; Pantoni et al. in prep.) is still under discussion.

II. **UNIFORM FLUX REDISTRIBUTION**
The basic idea is redistributing uniformly the amount of flux that is filtered out on a global scale, by comparing with Planck HFI4 (1.38 mm).

NGC4254: large-scale emission filtering

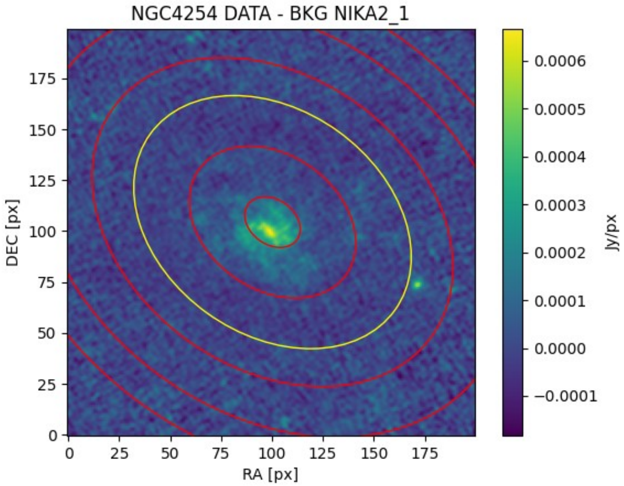
UNIFORM FLUX REDISTRIBUTION

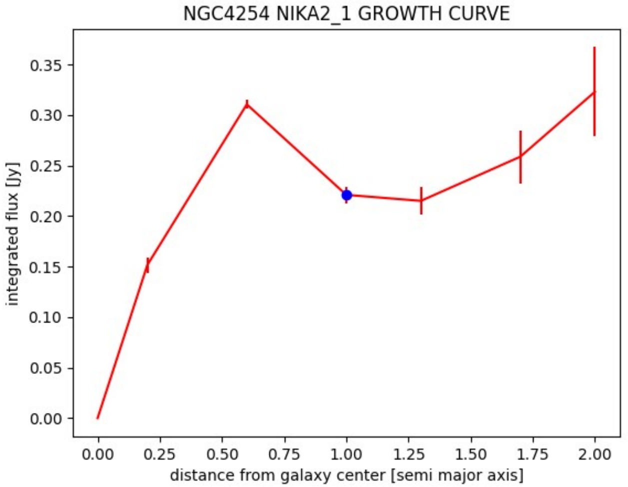
The basic idea is redistributing uniformely the amount of flux that is filtered out on a global scale, by comparing with Planck HFI4 (1.38 mm).

- Planck 1.38mm integrated flux (bkg-subtracted) is extrapolated to 1.15mm and 2mm as $\boldsymbol{\nu}^{2+\beta}$, where **β is randomly chosen** from a uniform distribution defined in the range $\mathbf{1} < \boldsymbol{\beta} < \mathbf{2}$. This is done N times: the mean values give the extrapolated fluxes at NIKA2 wavelengths.
- This allows us to get the integrated flux at 1.15mm and 2mm (NGC4254 is not detected by HFI5, 2mm) as it was observed from space.
- A color-correction which takes into account the different filter's shapes and central wavelengths is also used for comparison (at 1.15mm): the two global fluxes match perfectly ($\sim$ 0.7 Jy).
- We assume a **uniform flux filtering across the galaxy**, so that the amount of *flux lost* (i.e. flux extrapolated from HFI4 *minus* NIKA2 flux) is **equally redistributed within the pixels** where we see the galaxy emission and added back.
- **Uncertainties** are propagated through **MC method**.

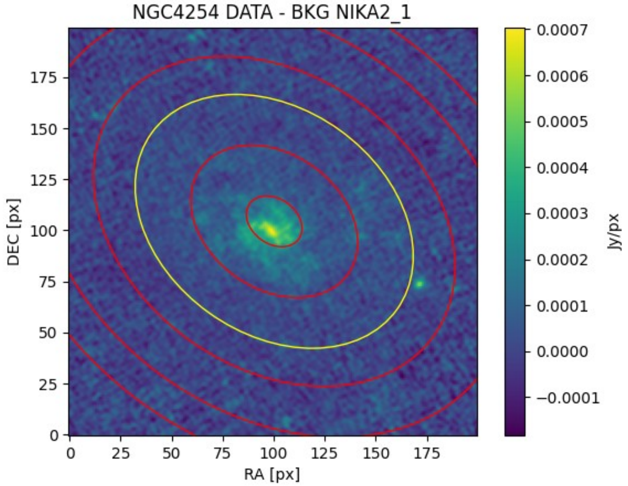
Pantoni et al. in prep.

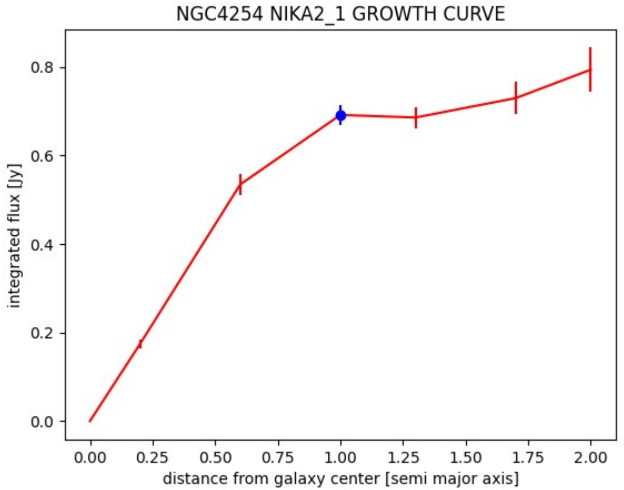
ORIGINAL





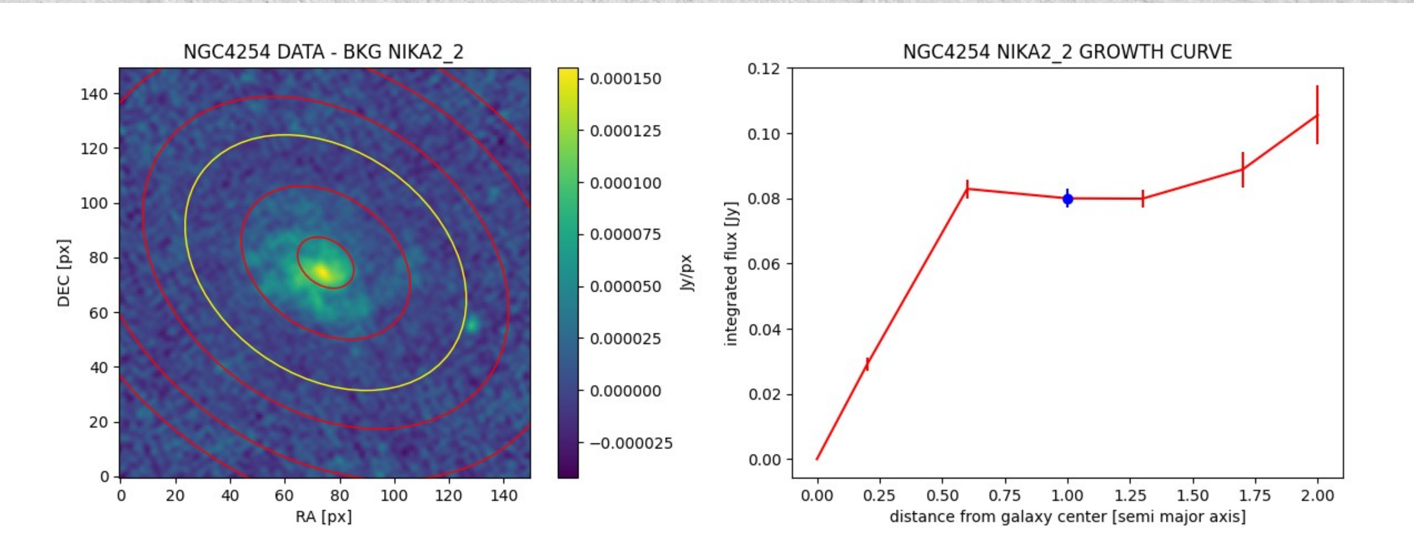
RESTORED





Pantoni et al. in prep.

ORIGINAL



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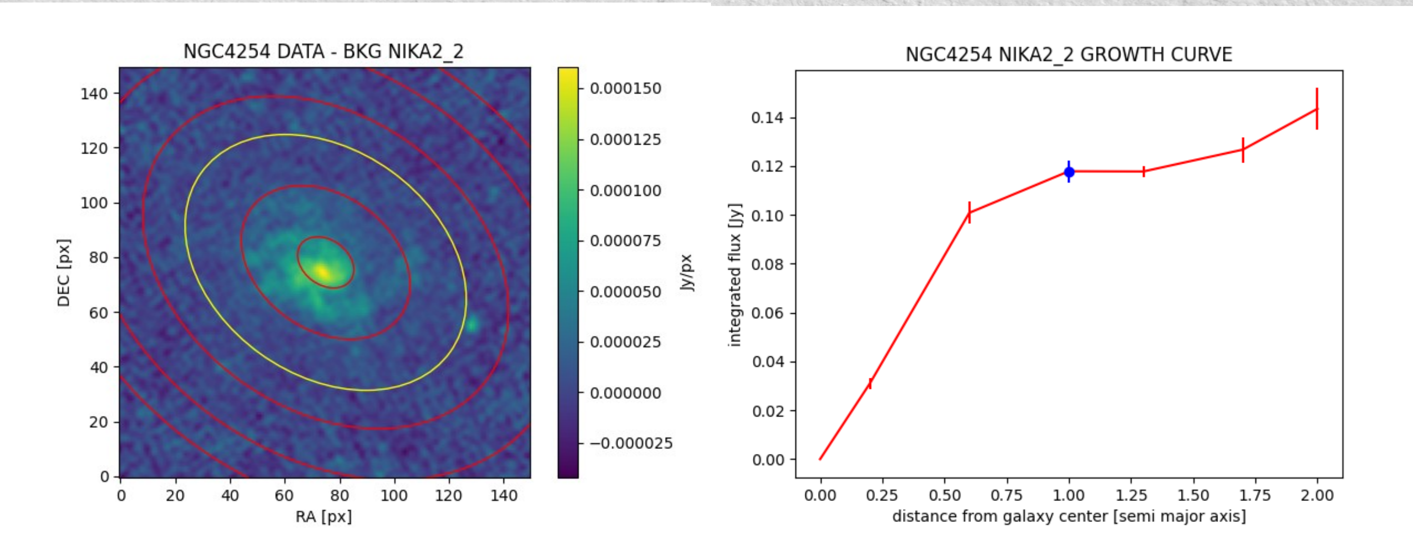
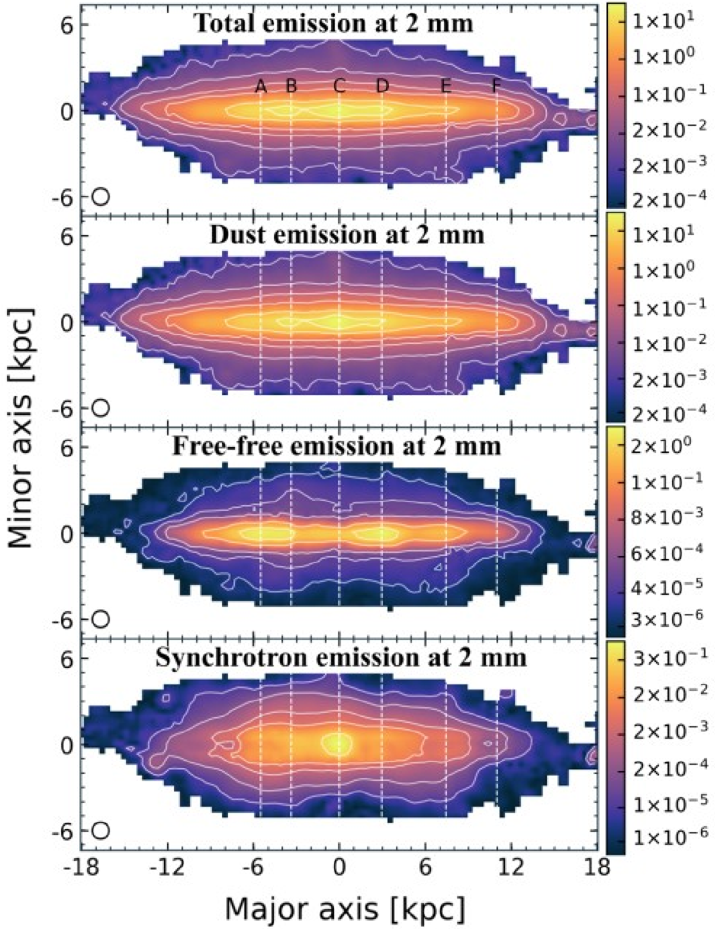


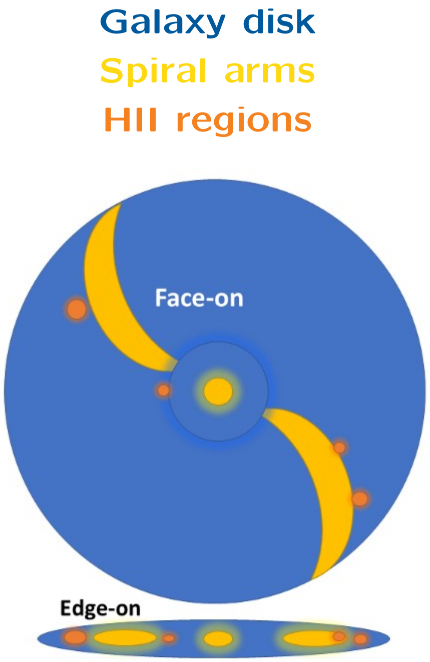
Pantoni et al. in prep.

NGC891: the stratification of ISM properties



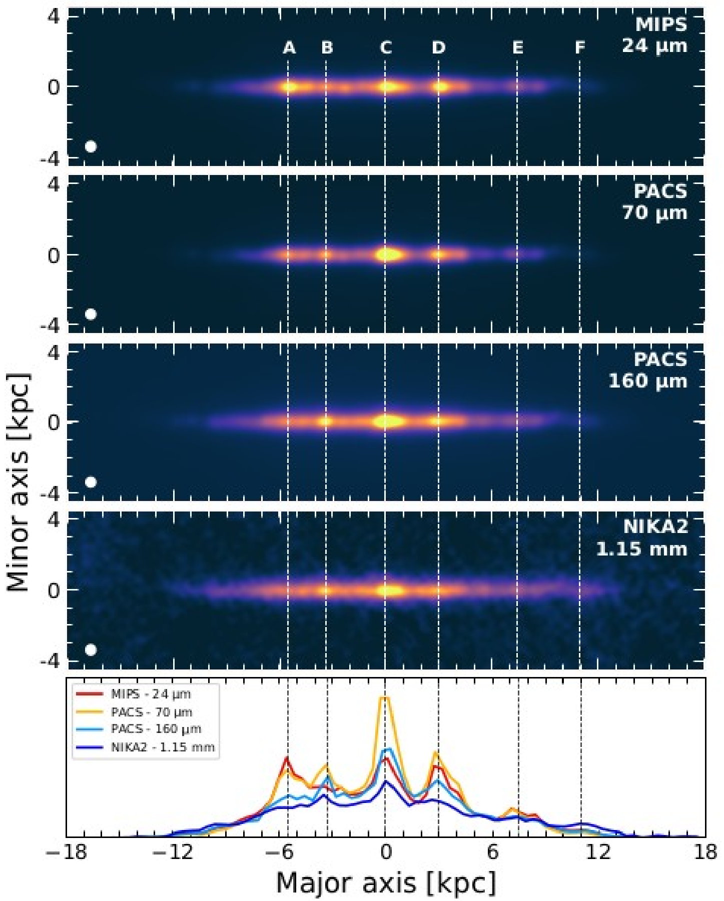
NIKA2 2mm map decomposed into **dust emission (91%)**, **free-free (5%)** and **synchrotron (4%)**; 1mm map is dominated by dust.

- Dust, free-free and synchrotron show different morphologies.
- Prominent halo component, up to 5 kpc.
- Three peaks (B, C, D).
- Free-free penut-shaped halo, deficit in C.
- Synchrotron ehnanched in C, drops off towards the outer regions.



Katsioli et al. 2023

NGC891: the stratification of ISM properties



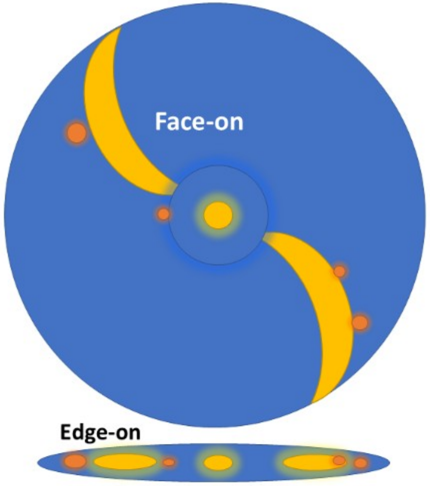
Flux profiles of MIPS 24µm, PACS 70µm, 160µm and NIKA 1mm along the major axis.

Bright spots and areas are the reprojection of HII regions and spiral arms.

The relative differences in flux profiles (normalized at 6kpc in a free region) gives indications on the distribution of the different dust components.

Warmer dust (MIPS, PACS; red and yellow profiles) is concentrated in the central regions and particularly in HII regions; **cold dust** is dominant in the outer disk (NIKA2; blue).

Galaxy disk
Spiral arms
HII regions

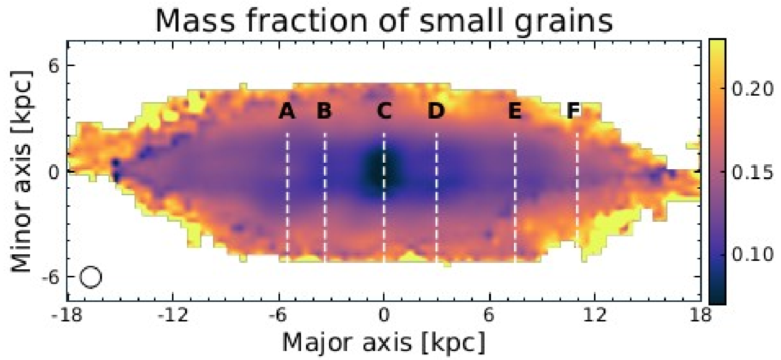


Katsioli et al. 2023

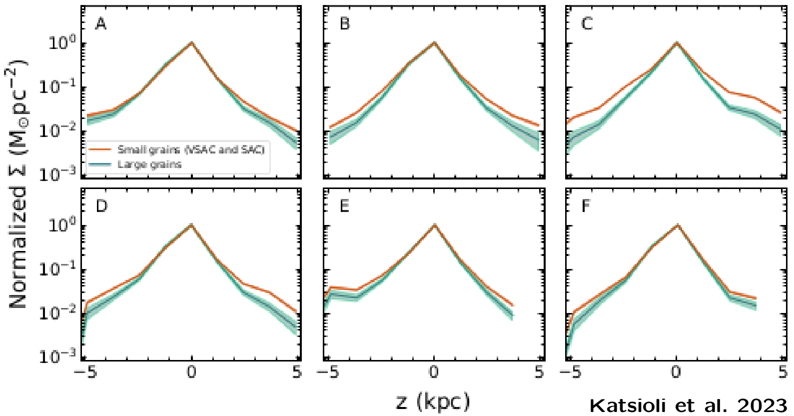
NGC891: the stratification of ISM properties

At **large vertical distances** (> 2 kpc) the mass of small grains is $>$ **20%,** while it attaints to values $\sim 5\%$ in the bulge and up to $\sim 15\%$ in the ehnached regions.

Small grains mass surface density shows a **shallower profile with vertical scale high** than large grains.



Small and large grains vertical profiles of mass surface density normalized at z=0 kpc



Katsioli et al. 2023

Note: small dust grains in THEMIS (and HerBIE) are amorphos and partially hydrogenated carbons of size **a** $<$ **1.5 nm**.