Study of the ISM properties of nearby galaxies through their emission at millimeter wavelengths

Stavroula Katsioli
Department of Physics, UOA & IAASARS, NOA

& IMEGIN team
on behalf of the NIKA2 collaboration

Outline

- **Introduction**
- **Methodology**
- **Discussion of the results**
  I. Millimeter excess?
  II. Emission decomposition at mm/cm wavelengths
  III. Distribution of warm and cold dust
  IV. Distribution of small and large grains
- **Conclusions & ongoing study**

IMEGIN – **I**nterpreting the **M**illimeter **E**mission of **G**alaxies with **I**RAM and **N**IKA2

P.I.: S. Madden

IMEGIN LP is a Guaranteed-Time Large Program of the NIKA2 collaboration. We have observed **18 nearby galaxies** (distance < 30 Mpc) at **1.15 and 2 mm** using the **NIKA2 camera** (Bourrion et al. 2016; Calvo et al. 2016; Adam et al. 2018) on the IRAM 30-m telescope (Pico Veleta, Sierra Nevada).

Program objectives:

- **Galactic chemical evolution understanding** through the distribution of the stars and the ISM ingredients (gas and dust) within the galaxies.
- **Observing dust emission**, as dust is an essential ISM ingredient for star formation activity, despite its insignificant mass.
- **Unveiling the uncharted millimeter regime**, revealing the presence of not only thermal dust emission, but also contributions from synchrotron and Bremmstrahlung radiation (free-free).

iram Institut de Radioastronomie Millimétrique NIKA2

NGC 891 properties	
UGC catalog number:	1831
Coordinates:	$\alpha_{J2000} = 2^h22^m33^s.0028$ $\delta_{J2000} = +42°20'52''.996$
Type:	SA(s)b
Distance:	9.6 Mpc
Inclination:	89.8°
Position angle:	22.9°

Table 1: Fundamentals properties of NGC 891; Bianchi & Xilouris (2011).

Source:
https://apod.nasa.gov/apod/

Observations

Reduction: **PIIC/GILDAS**
Telescope time: ~7 hours

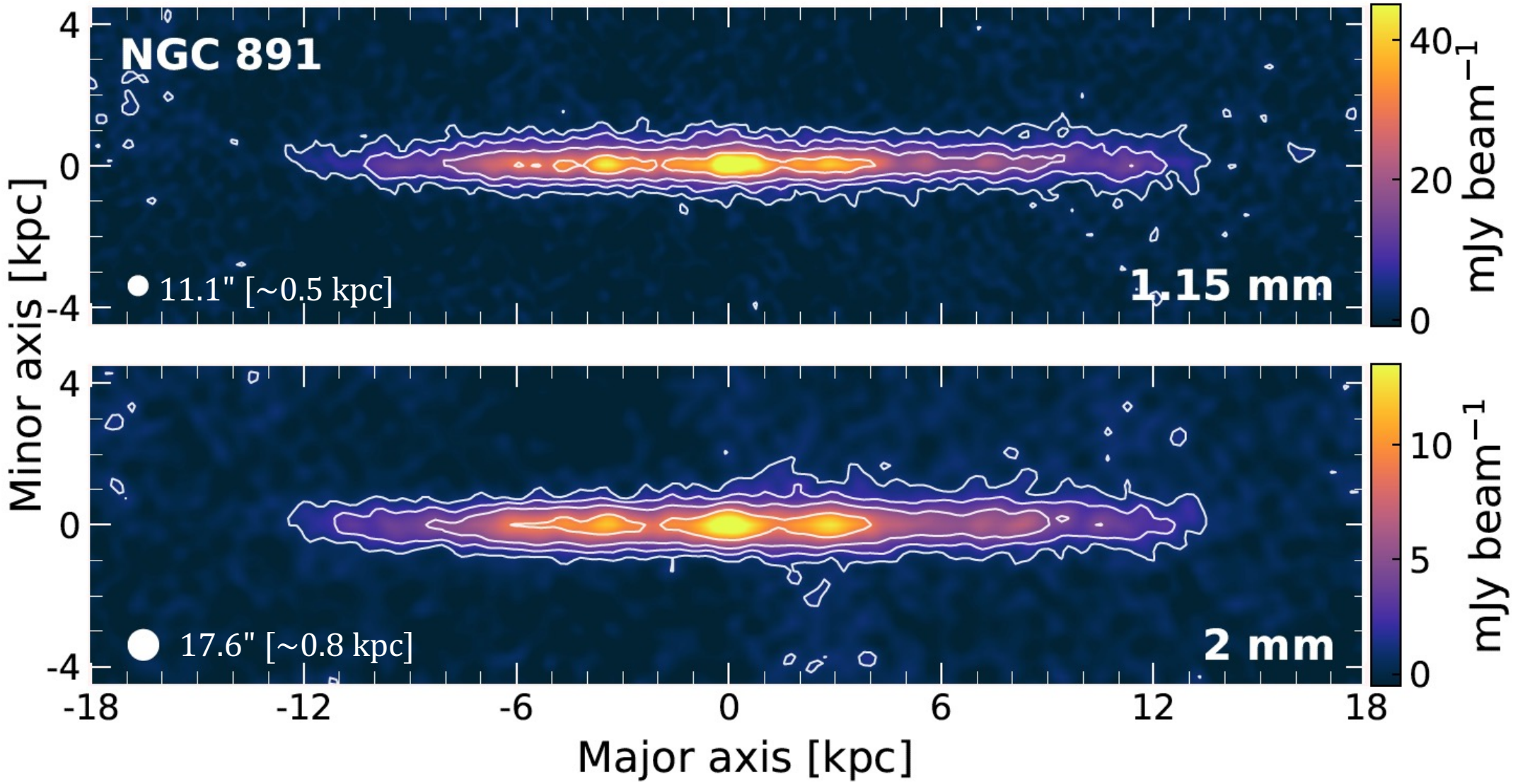

Fig. 1 in Katsioli et al., A&A, submitted

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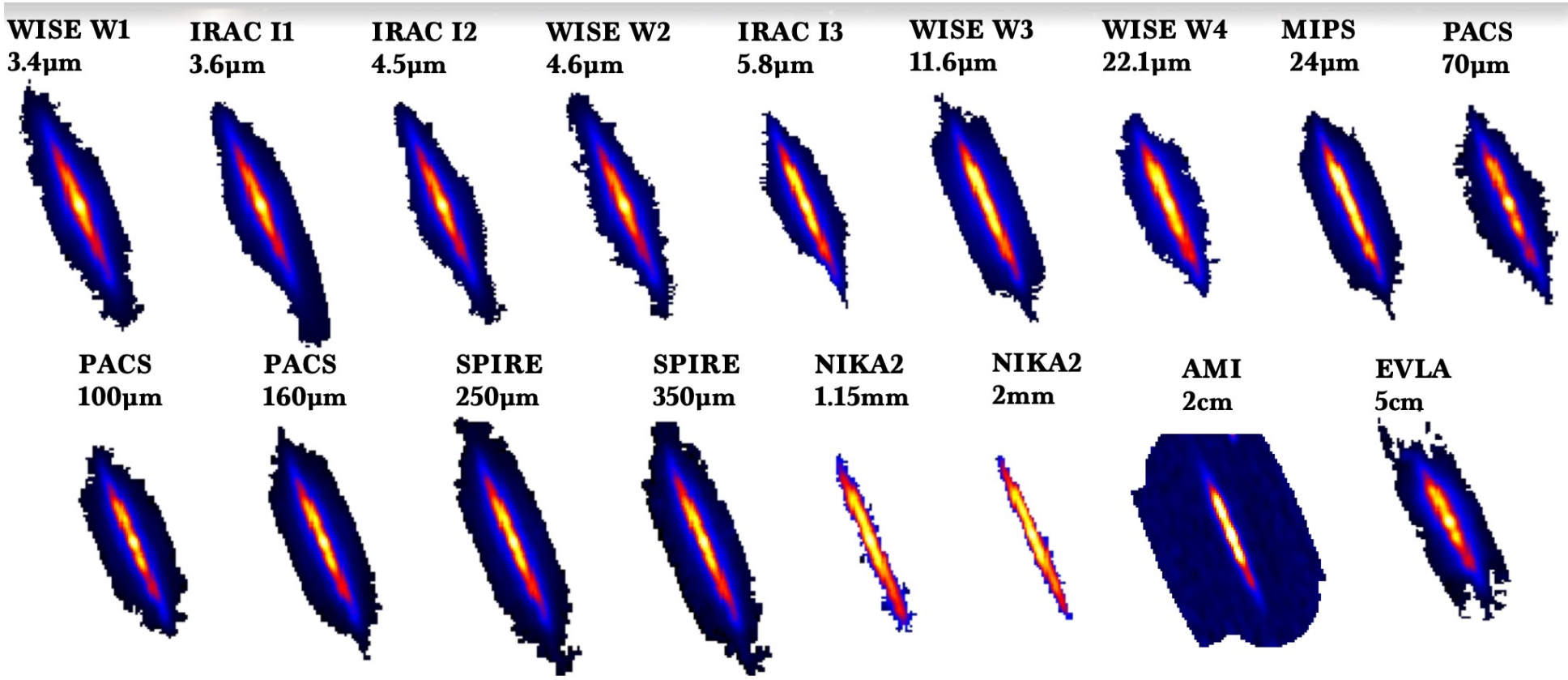
Data pre-treatment

Photometrical data:

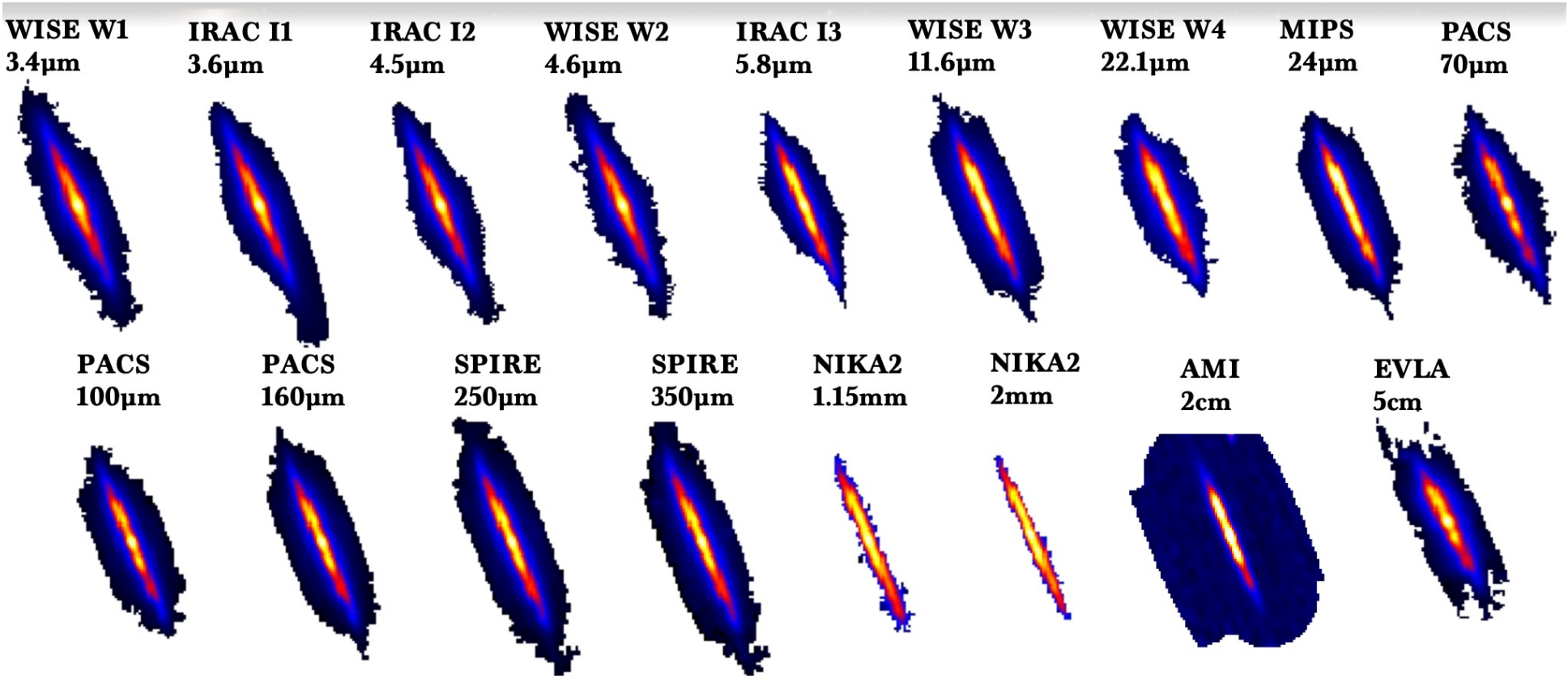
- ranging in wavelength: [3.5µm, 6cm]
- telescopes: WISE, *Spitzer*, *Herschel*, **IRAM 30-m**, *Planck*, AMI, OVRO, GBT, *Effelsberg* 100-m, EVLA, WSRT



Global photometry:

- aperture photometry using an ellipse centered at RAJ2000 = $2^h22^m33^s$, DECJ2000 = +42°20'53" with major and minor axes of 5' and 48" respectively

Data pre-treatment



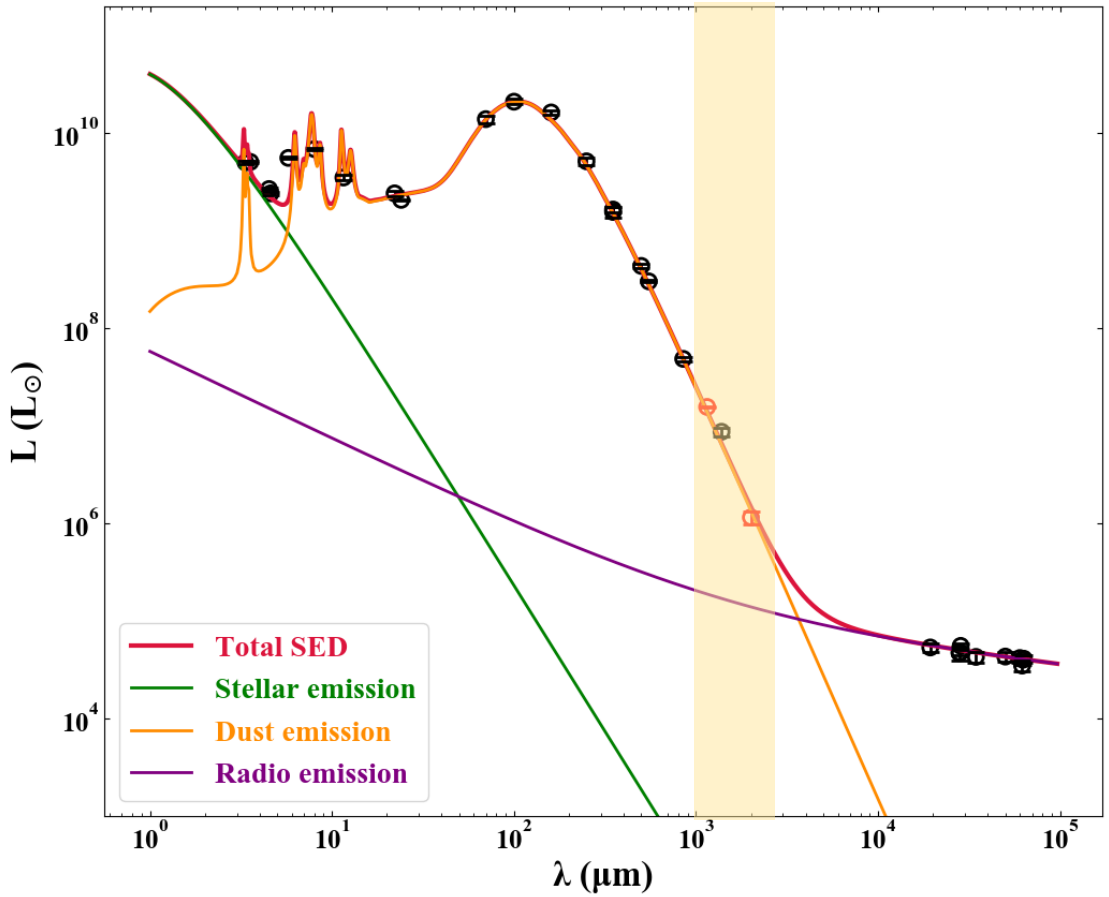
Resolved maps:

- converted to the same units
- background subtraction as described in Verstocken et al. 2020
- degraded to the lowest available resolution (FWHM~25")
- regridded to a common frame (8" pixelscale)
- applied a 3σ cutoff
- NIKA2 maps: CO (2-1) line emission subtracted (~3%)

Method for our analysis: SED fitting

The SED fitting code: **HerBIE**

(Galliano 2018; Galliano et al. 2021)



Why HerBIE?

The fitting code takes into account:

- realistic optical properties of the dust grains
- stochastic heating
- mixing of the physical conditions in the interstellar regions
- distribution of starlight intensities
- color correction
- calibration uncertainties

The hierarchical Bayesian approach recovers the true correlations of the parameters suppressing the noise-induced, false correlations.

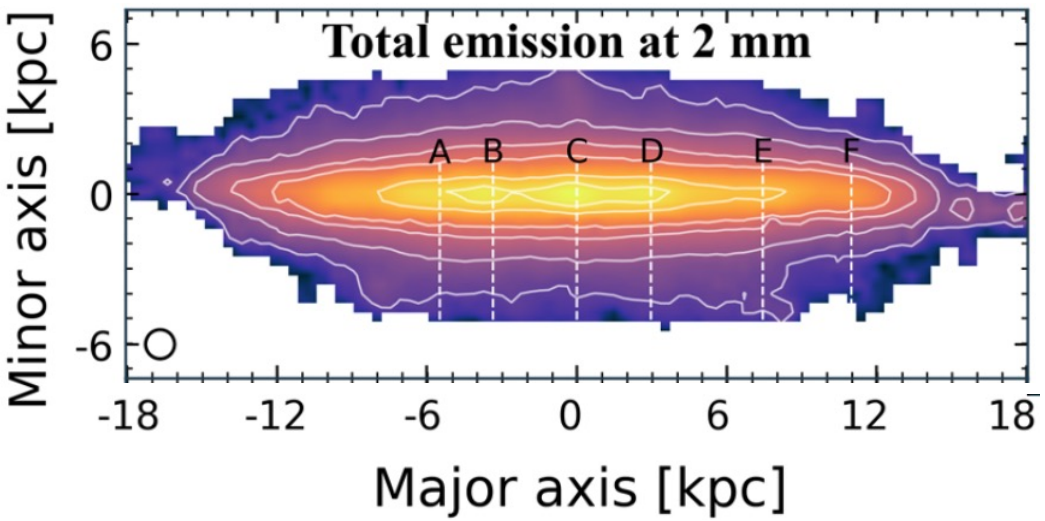
SED (Spectral Energy Distribution) fitting

- **globally**
- **spatially (pixel-by-pixel/whole galaxy inside 3σ)**

Presentation of 6 SEDs examples from 6 pixels in the regions of interest A-F

SED fitting code: `HerBIE`

angular size of a pixel: **8"**
physical size of a pixel: **0.37 kpc**



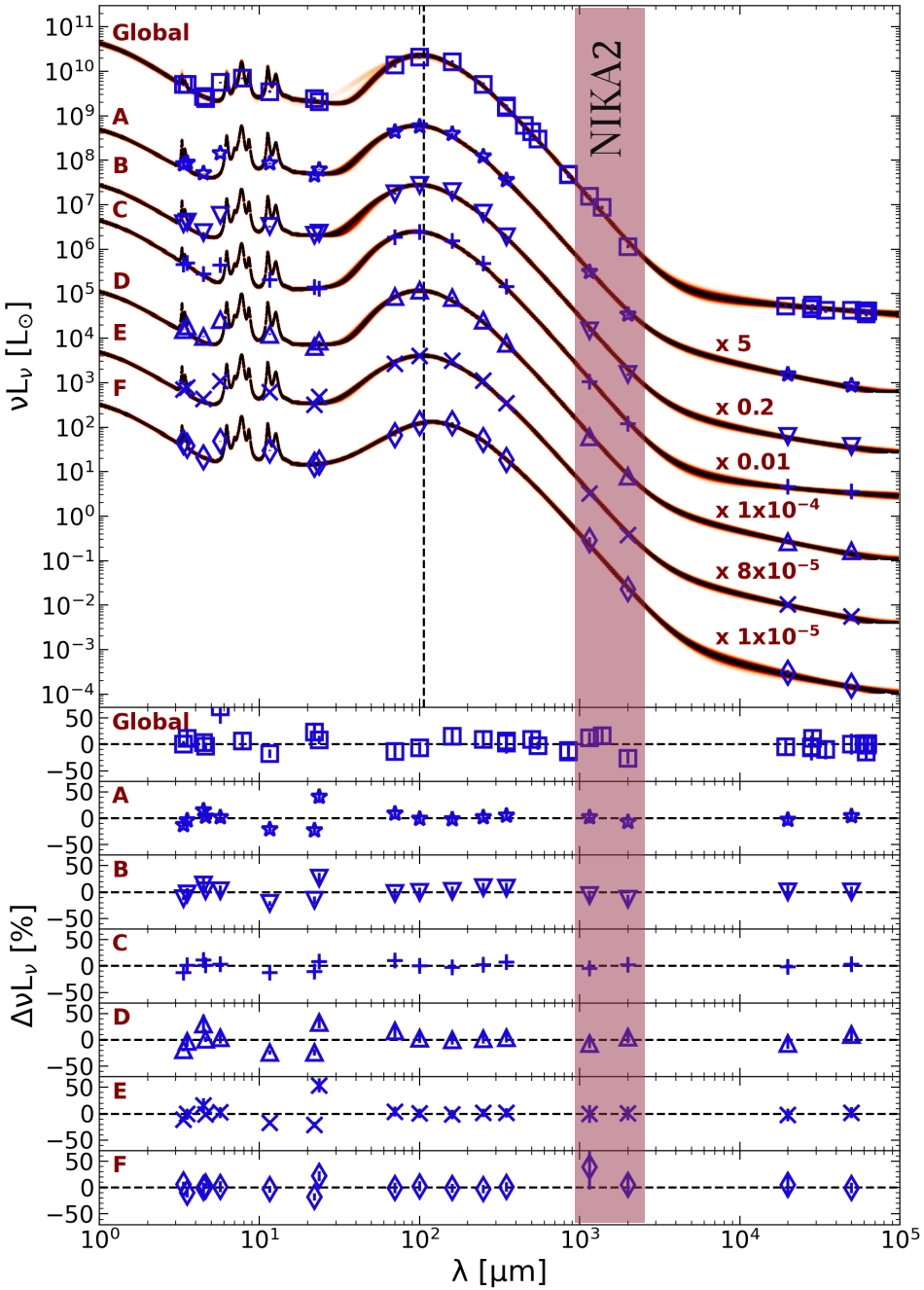


Fig. 2 in Katsioli et al., A&A, submitted

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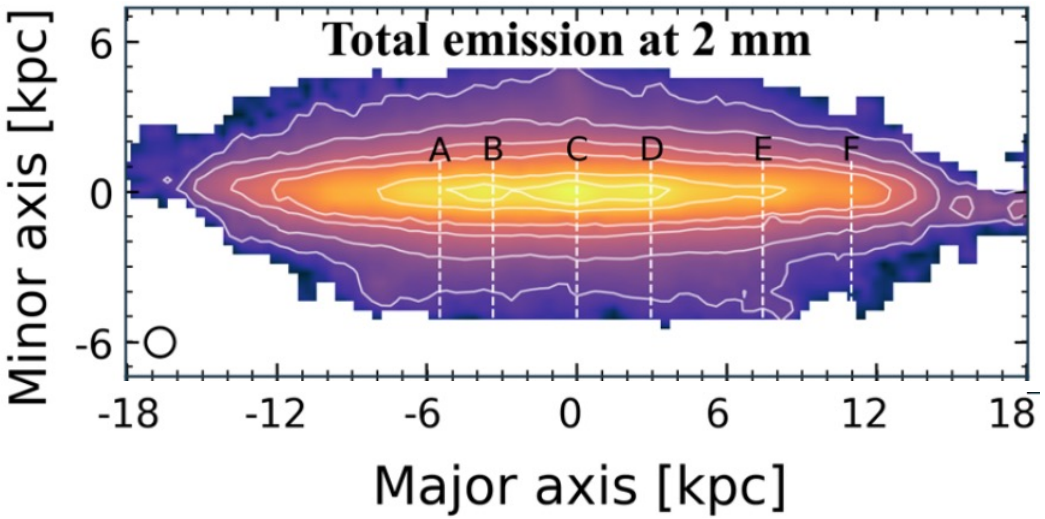

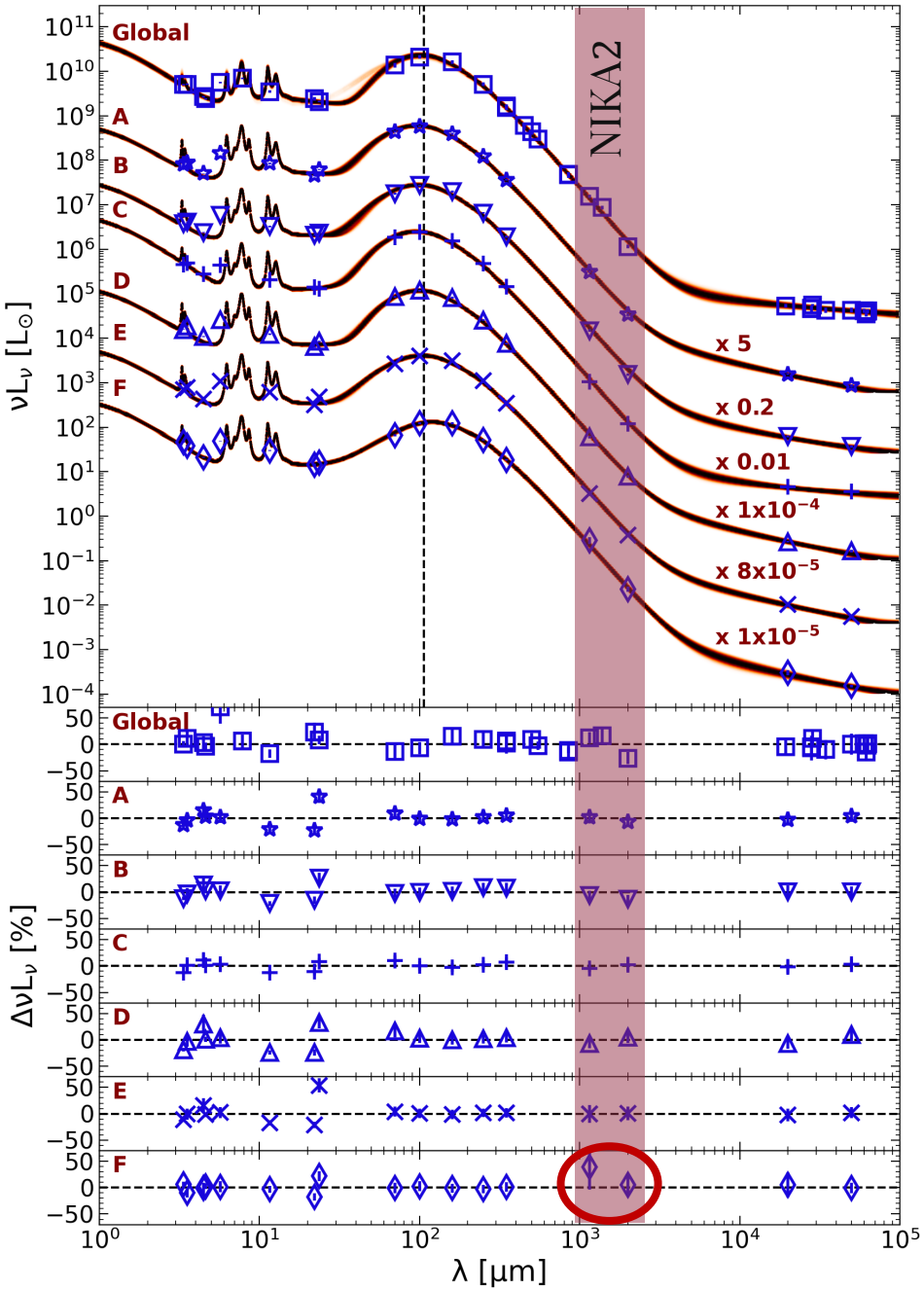

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I. Millimeter excess?

Residuals between observation and model at 1.15 mm and 2 mm

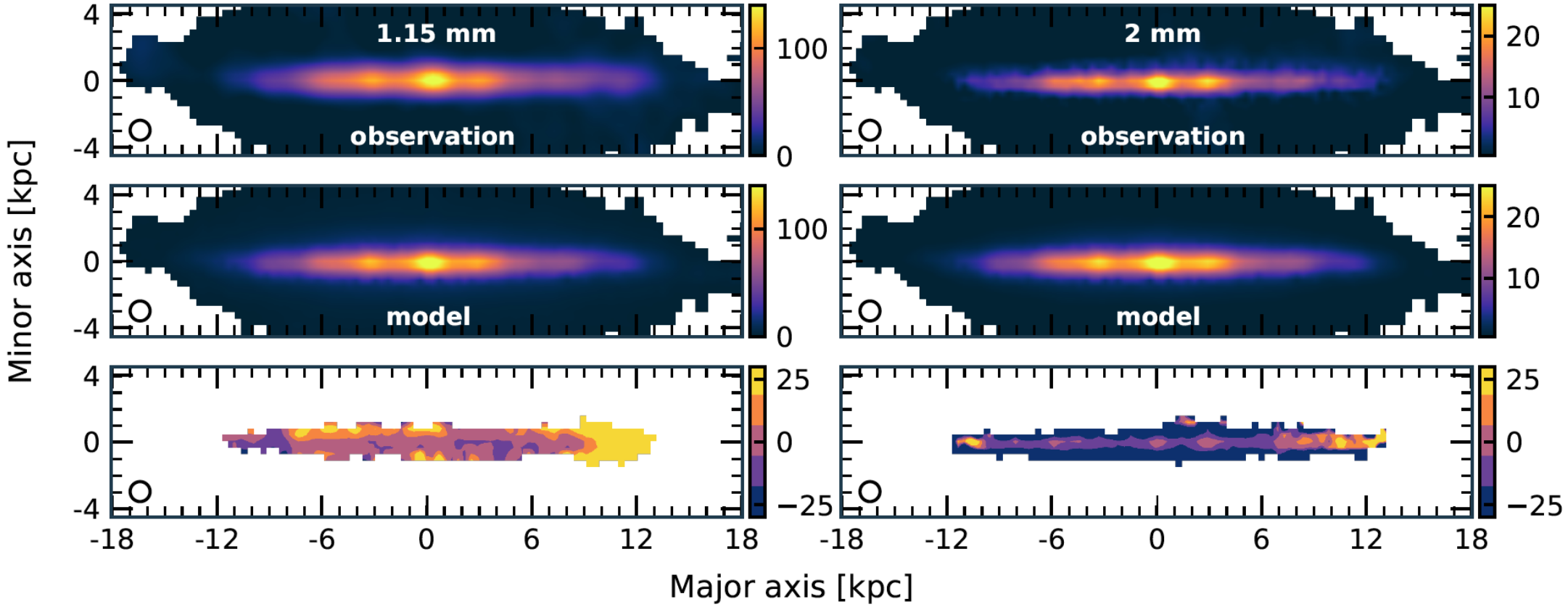

Fig. 3 in Katsioli et al., A&A, submitted

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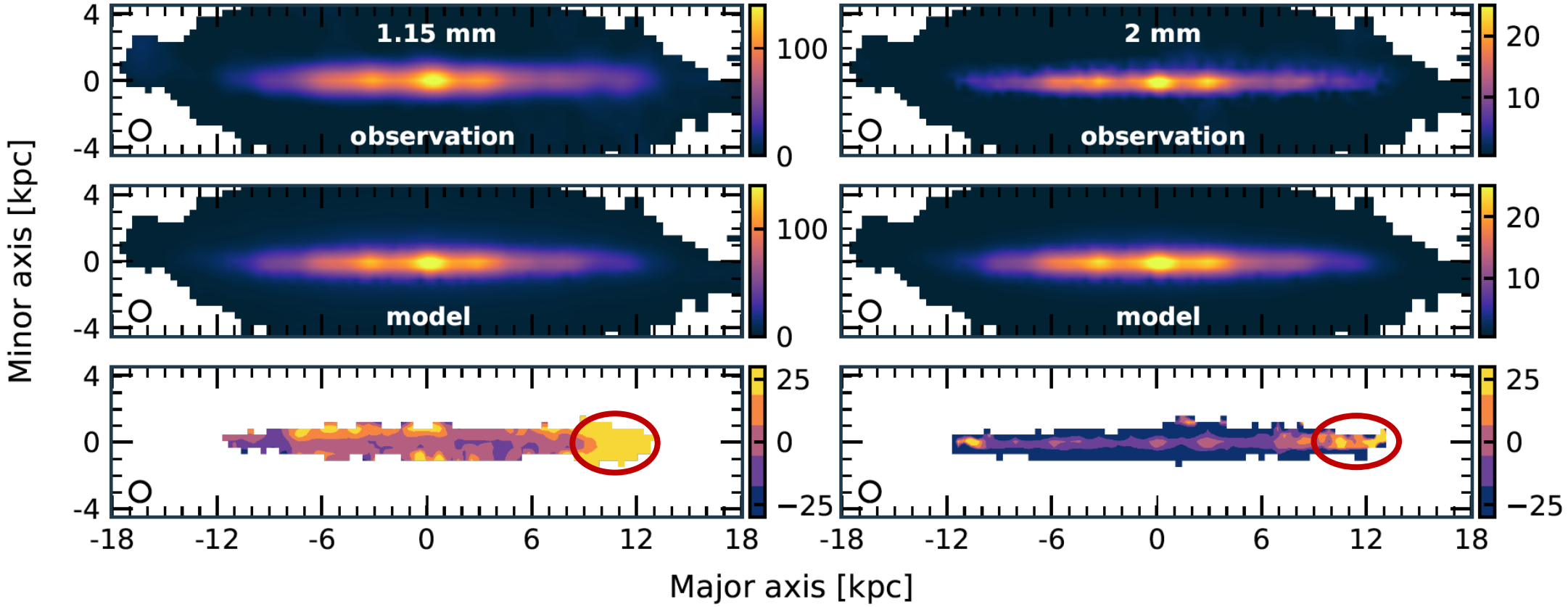

Fig. 3 in Katsioli et al., A&A, submitted

Indication of an excess emission towards the disk outskirts

I. Millimeter excess?

Residuals between observation and model at 1.15 mm and 2 mm

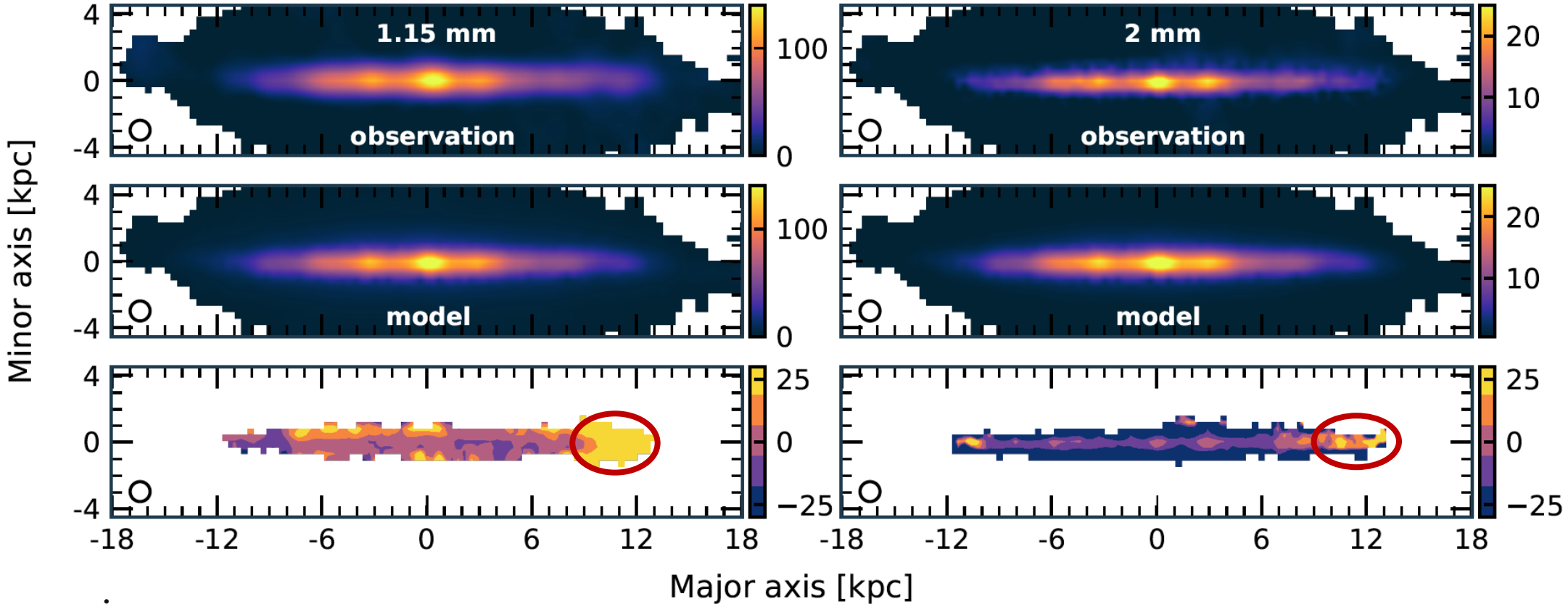

Fig. 3 in Katsioli et al., A&A, submitted

Possible scenarios:

- **very cold dust** (T~4K) → indication of past interactions
- other physical mechanisms have been proposed
  e.g. **temperature dependent emissivity** and/or **magnetic dust grains**
  (Sec. 3.5.5.2 of Galliano et al. 2018, for a review)

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II. Emission decomposition at mm/cm wavelengths

Free-free emission:
- associated with the ionised matter
- emitted by accelerated electrons inside the **electrostatic fields** of ions and nuclei

Synchrotron emission:
- accossiated with the magnetic field intensity
- produced by cosmic rays electrons propagating in interstellar **magnetic fields**

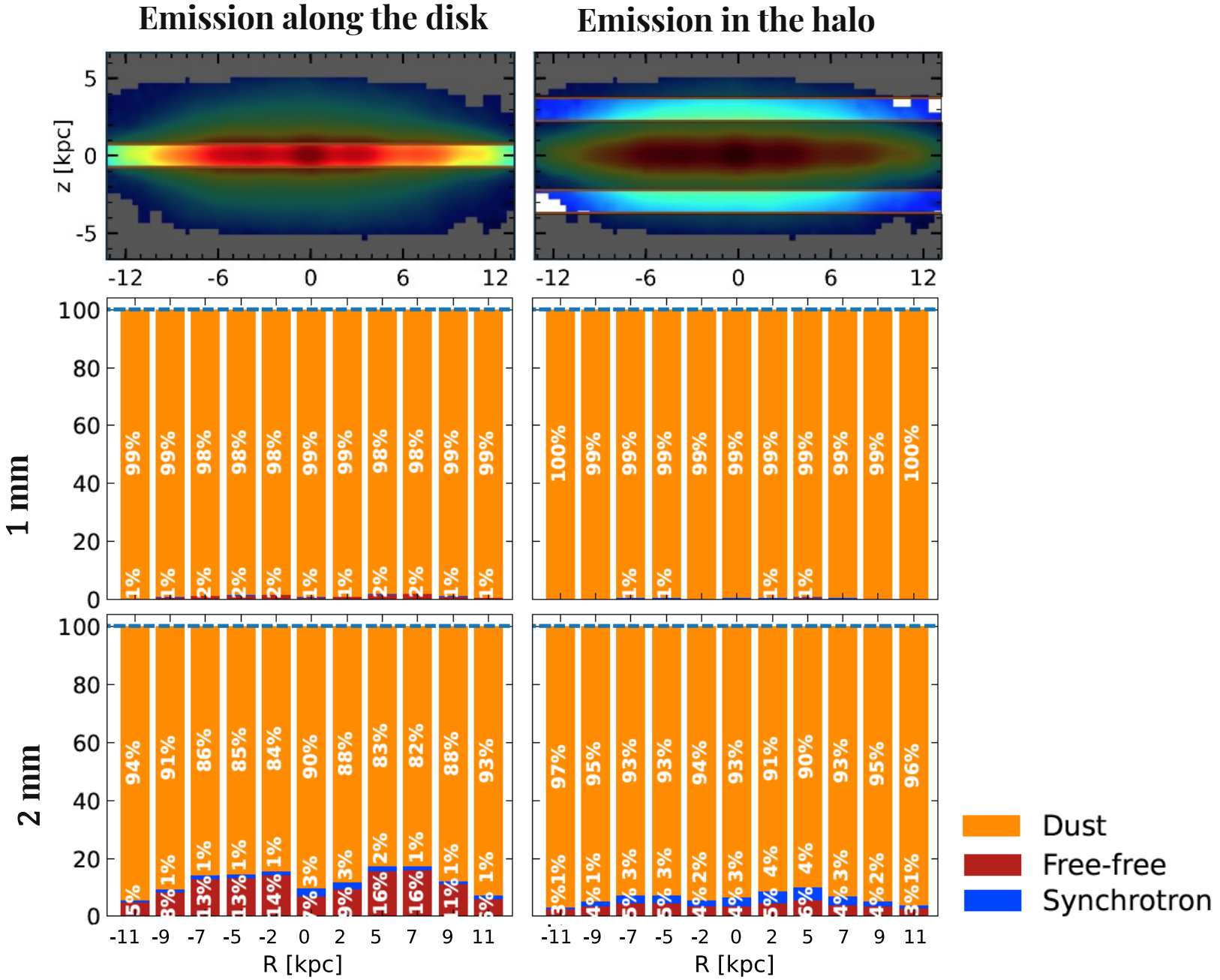
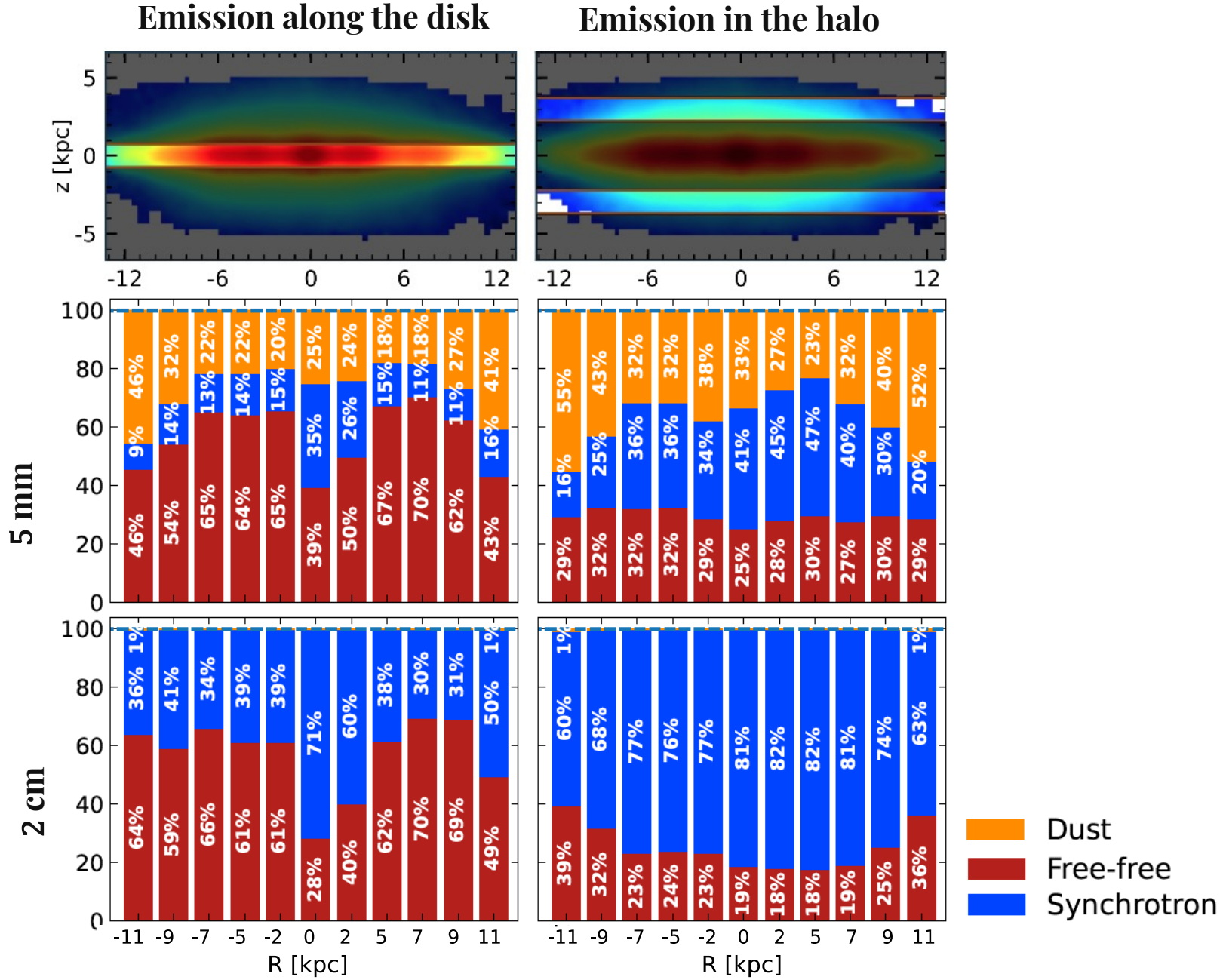


Fig. 5 in Katsioli et al., A&A, submitted

II. Emission decomposition at mm/cm wavelengths



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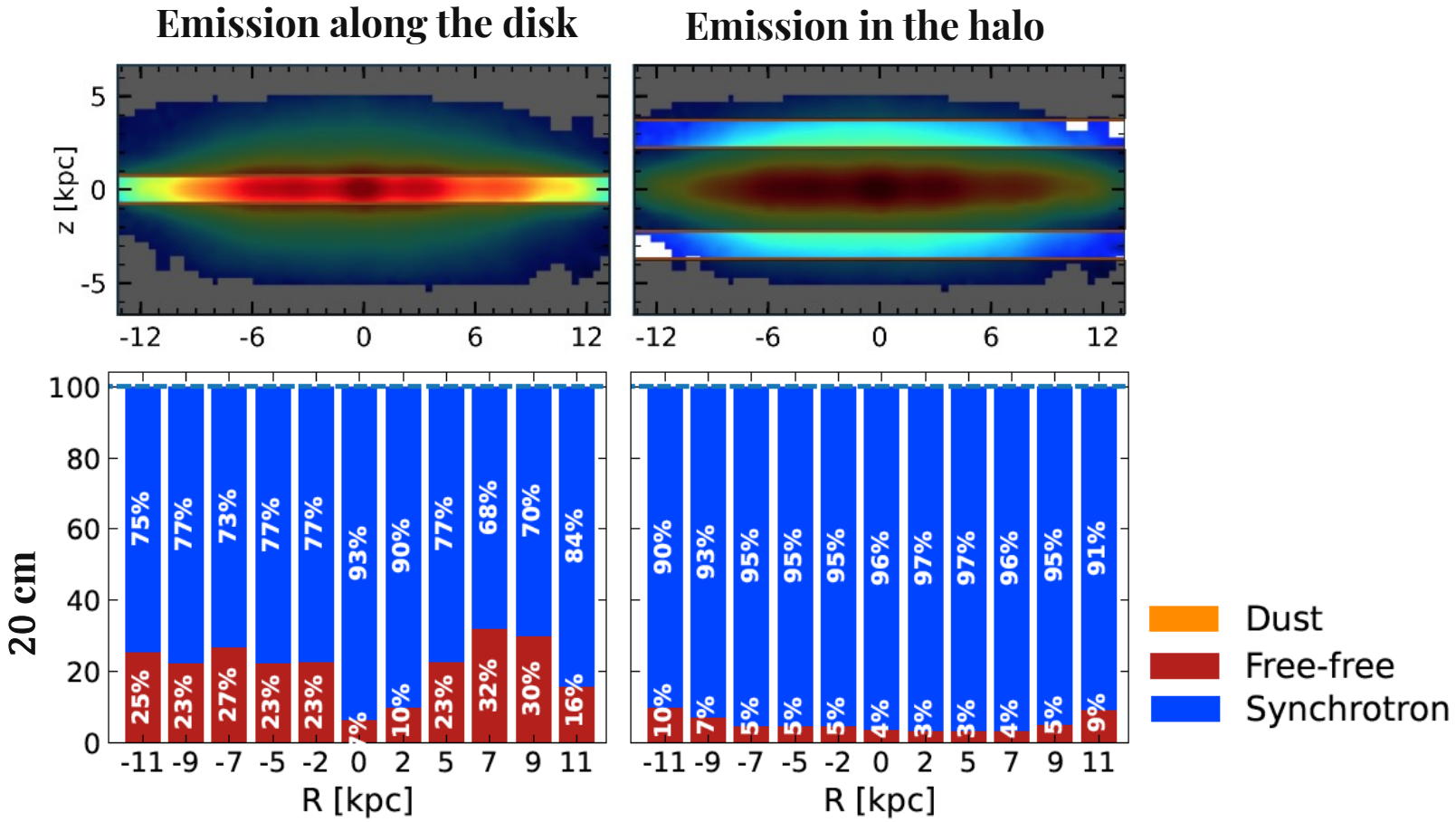

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III. Distribution of warm and cold dust

- We detect regions in the galactic disk seen only at MIR and only at FIR/mm
- Millimeter excess is detected again in the F region

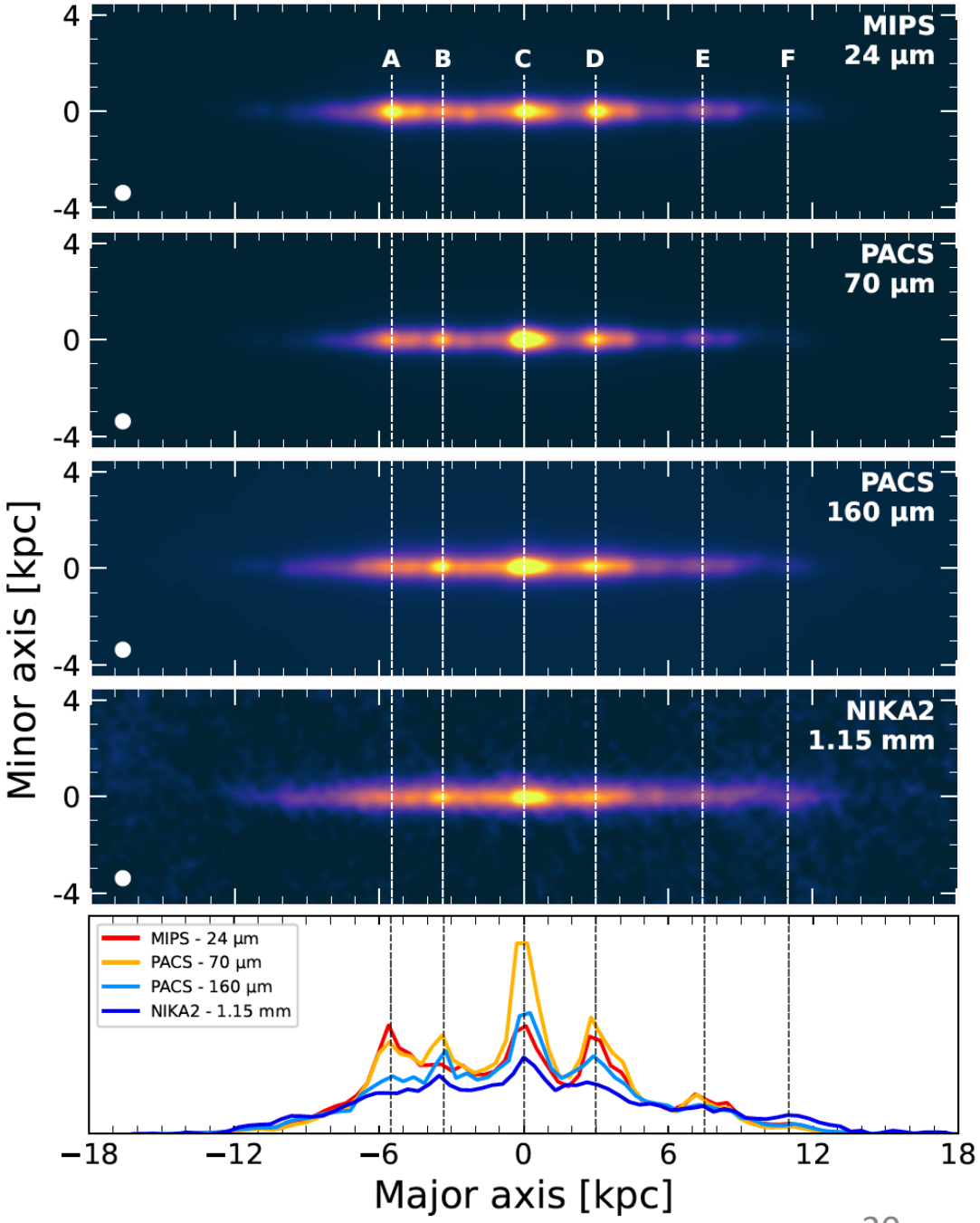


Fig. 6 in Katsioli et al., A&A, submitted

III. Distribution of warm and cold dust

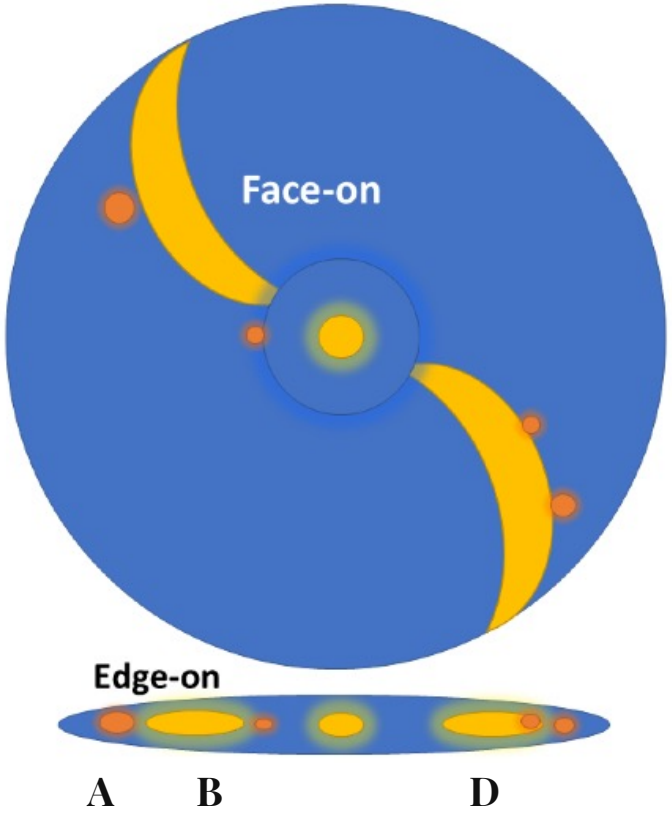
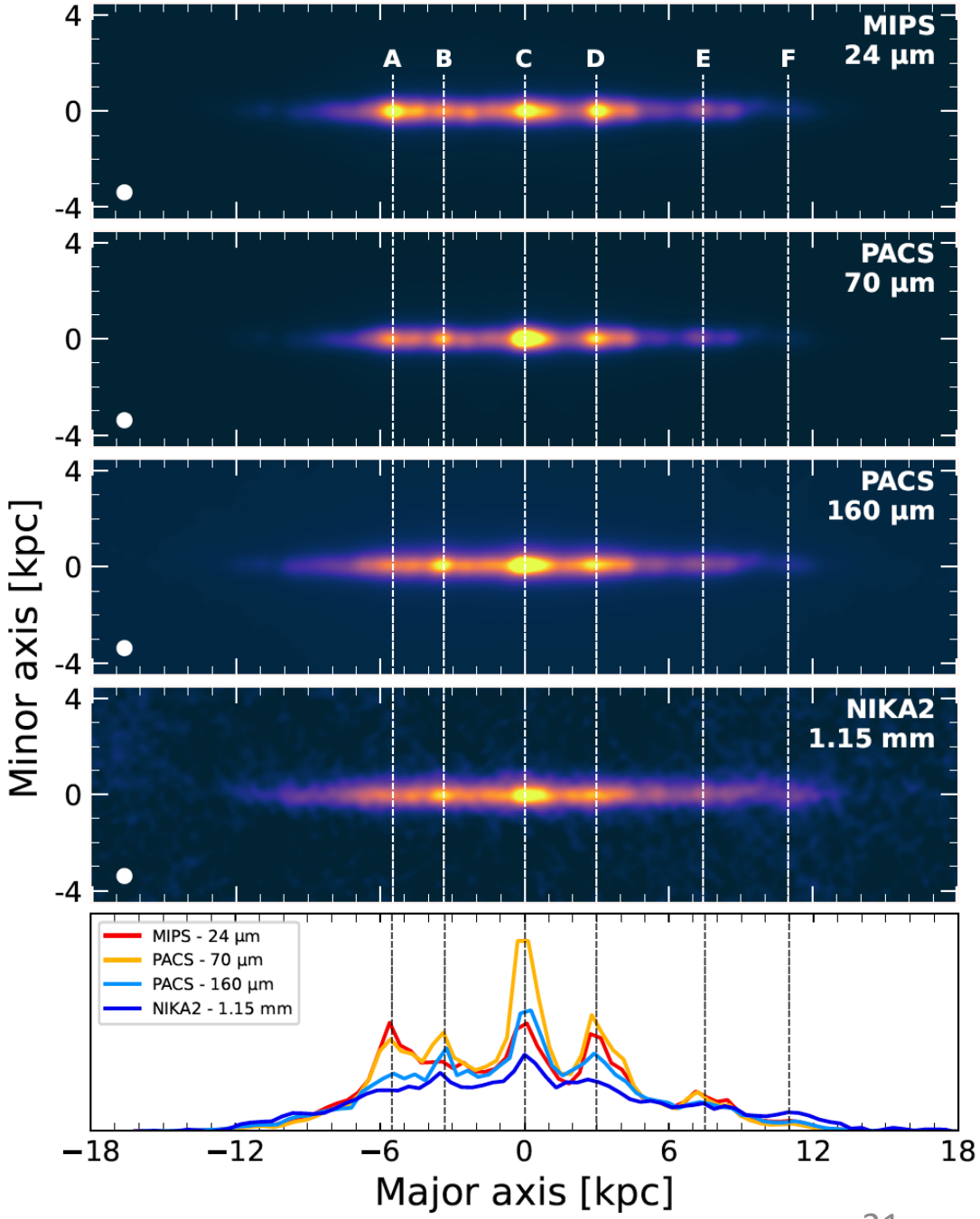


Fig. 7 in Katsioli et al., A&A, submitted



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IV. Distribution of small and large grains

THEMIS model implemented in HerBIE (based on laboratory data; Jones et al. 2013; 2017)

- **small grains**: very small (smaller than 7 Å; **VSAC**) and small grains (radius between 7 Å and 15 Å; **SAC**)
- **large grains**: medium and large grains (with radius larger than 15 Å; **MLAC**)

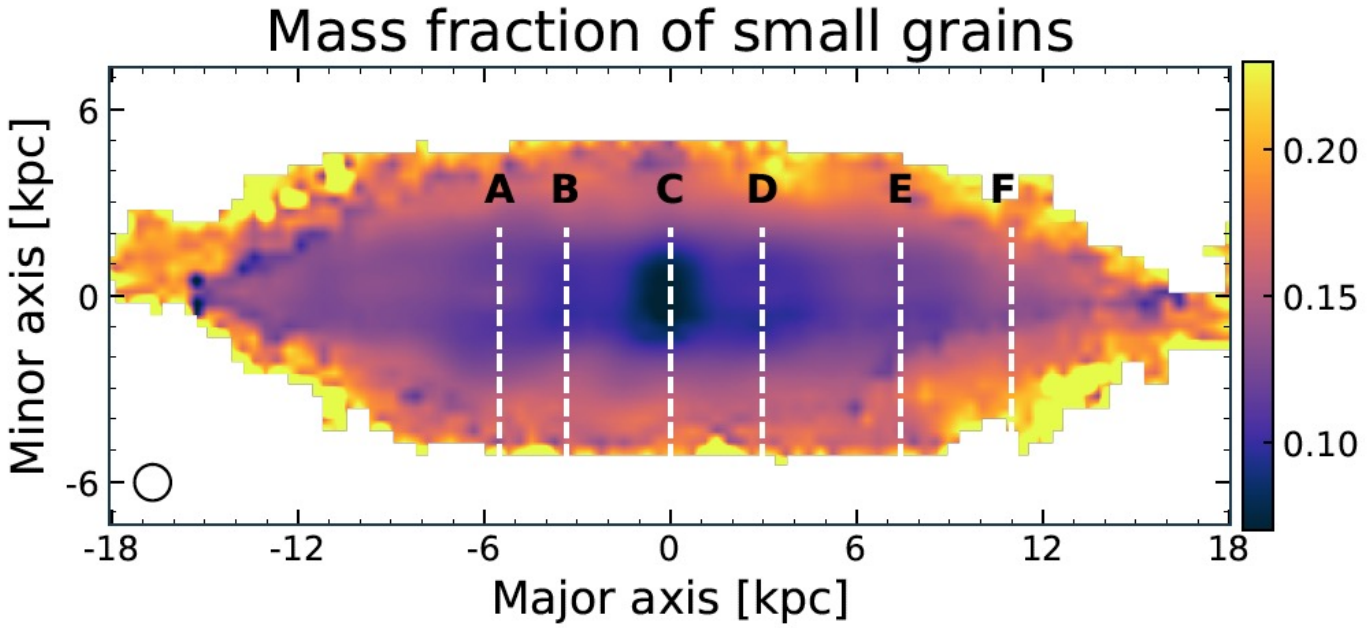


Fig. 8 in Katsioli et al., A&A, submitted

Chemical composition:
- small, partially hydrogenated, amorphous carbons, noted a-C(:H) [although largely dehydrogenated, small a-C(:H) are very similar to PAHs]
- large, a-C(:H)-coated, amorphous silicates with Fe and FeS nano-inclusions

IV. Distribution of small and large grains

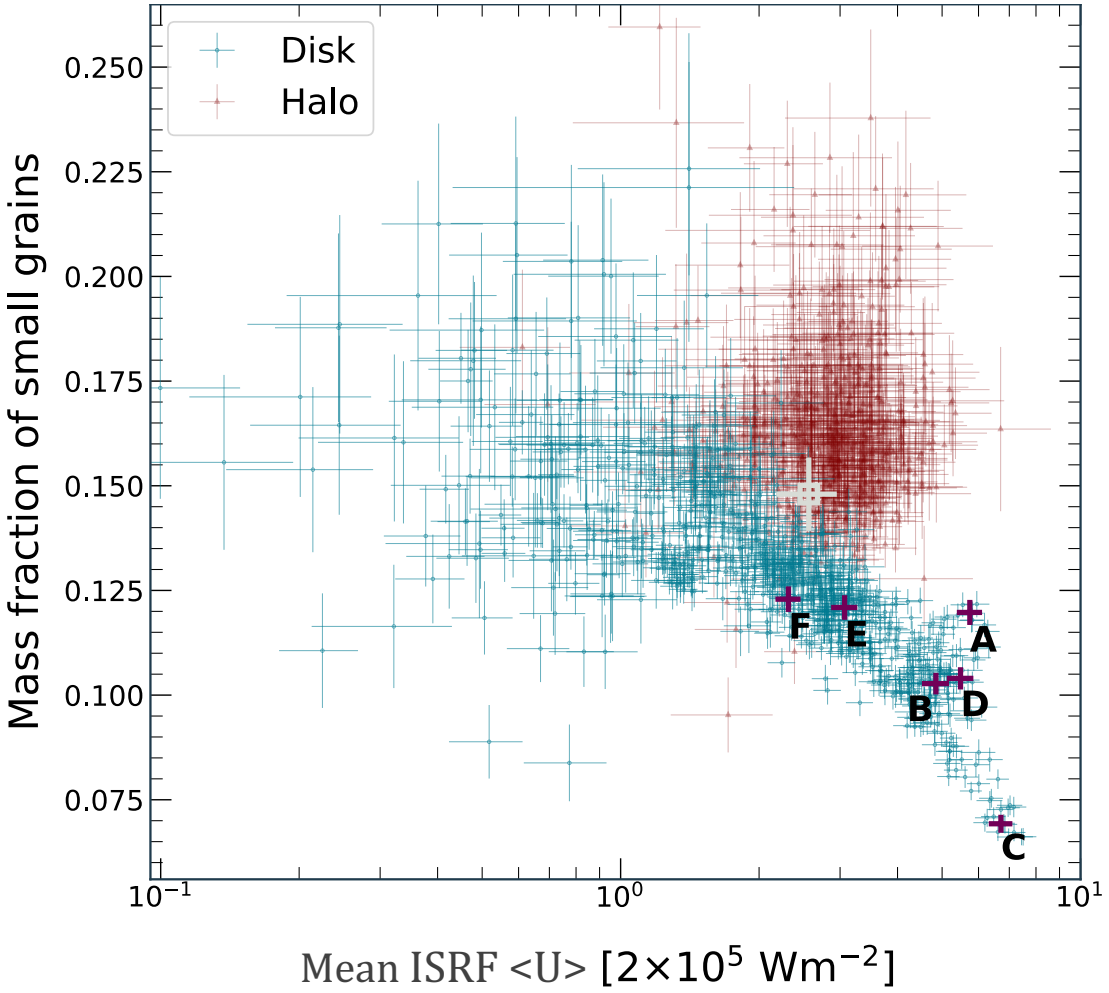


Fig. 9 in Katsioli et al., A&A, submitted

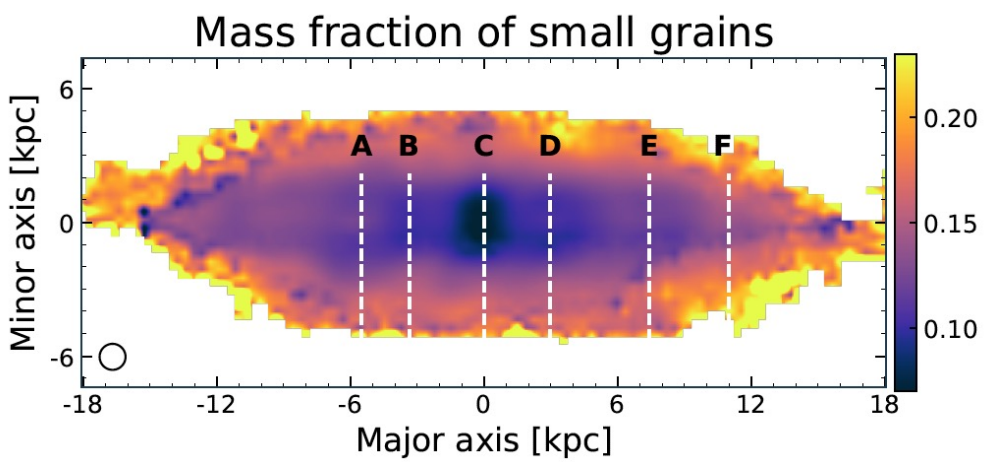
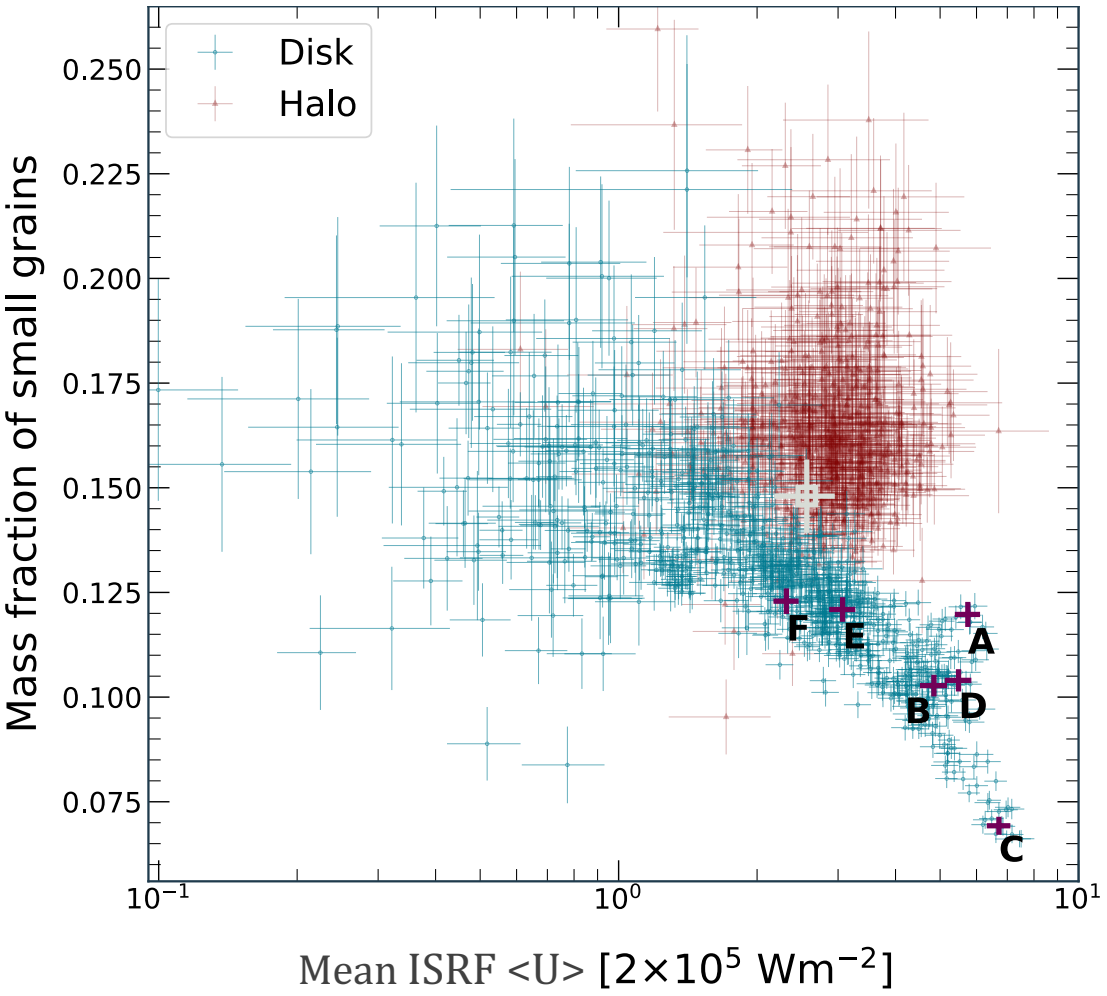


Fig. 8 in Katsioli et al., A&A, submitted

IV. Distribution of small and large grains



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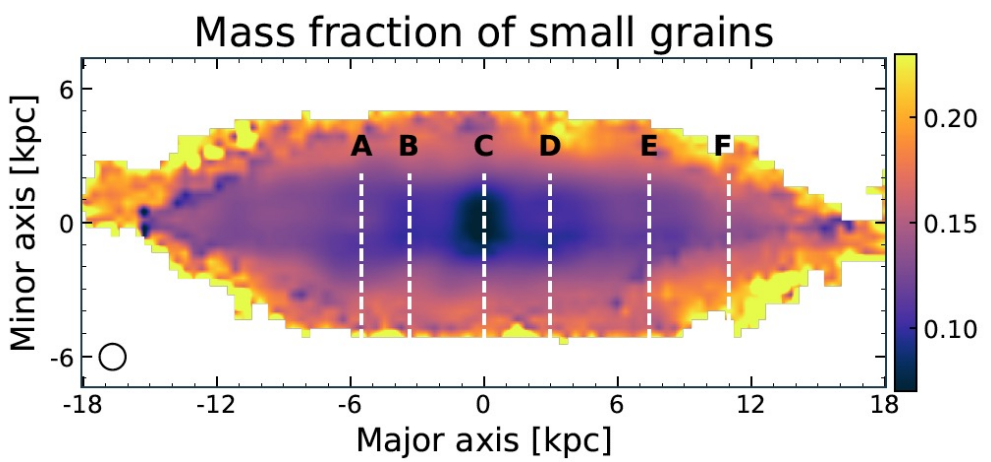

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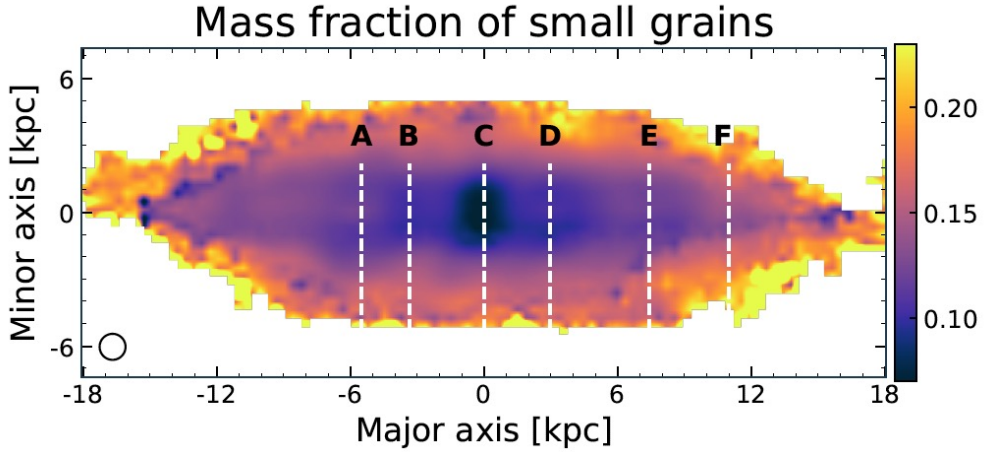
- **In the disk:** the anticorrelation probably results from the progressive destruction of these small grains by UV photons
- **In the halo:** we may see the grains expelled from the galaxy via outflows

IV. Distribution of small and large grains



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Vertical profiles of the **surface distribution of small and large grains** into the A-F regions of interest

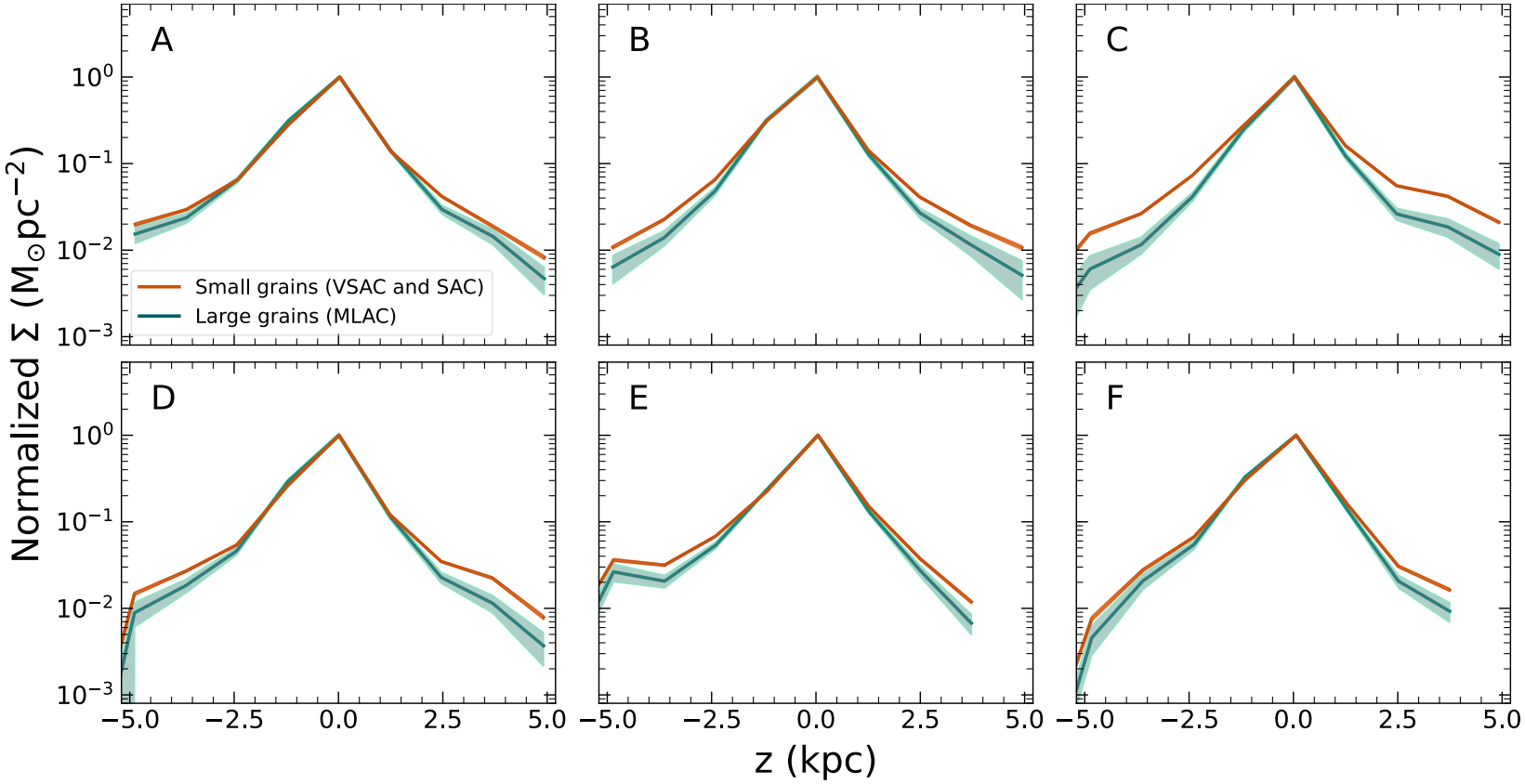

Fig. 10 in Katsioli et al., A&A, submitted

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Main conclusions for NGC 891

- There is **evidence of submm/mm dust emission in excess, at the outermost regions** with the NIKA2 fluxes above the model-predicted emission.

- The emission at mm/cm wavelengths is decomposed in detail. **At 1.15 mm the emission is coming from the dust with the free-free emission starts peaking up at 2 mm at levels of ~10-20%.** At 2 cm there is only radio emission with the **free-free emission dominating the disk and the synchrotron emission the halo**.

- **We detect regions in the galactic disk seen only at MIR wavelengths and only at FIR/mm wavelengths**. We explain this by a simple scenario with cold dust situated along the spiral arms of the galaxy, while warm dust arising from dust emission in compact HII regions.

- **We find that the mass fraction of the small grains is ~10% of the total dust mass in the disk of the galaxy.** At distances well above the galactic plane (~|z|>3 kpc) the mass fraction of small grains increase up to ~20%.

Ongoing study

- **Statistical analysis of the results for the full sample of the IMEGIN galaxies in order to determine how the different physical mechanisms participate to the different galactic environments.**


Thank you
for your attention!