Constraining Millimeter Dust Emission in Nearby Galaxies with NIKA2

Case of NGC2146 and NGC2976

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+ the IMEGIN consortium
+ the NIKA2 consortium

Outline

1. About IMEGIN
2. Get to know the galaxies!
3. NIKA2 observations
4. SED modeling
    a. Global SED modeling
    b. Resolved SED modeling
5. Gas in NGC2976
6. NIKA2 observation as SFR calibrator

IMEGIN

(**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 (Perotto+2020)
  PI: Suzanne Madden
- About 200 observing hours on the IRAM 30m telescope
- A sample of 20 galaxies with UV-radio complementary data

NGC327	NGC3627
NGC628	NGC3938
NGC891	NGC4254
NGC925	NGC4321
NGC2146	NGC4536
NGC2841	NGC5194
NGC2976	NGC6946
NGC3184	NGC7331
NGC3198	NGC3521

Goals:

- Study the emission at mm wavelengths and the physical processes causing it
- Study the relation of these processes to star formation
- To constrain galaxy SED spatially and study evolution of the dust emissivity and gas-to-dust ratio

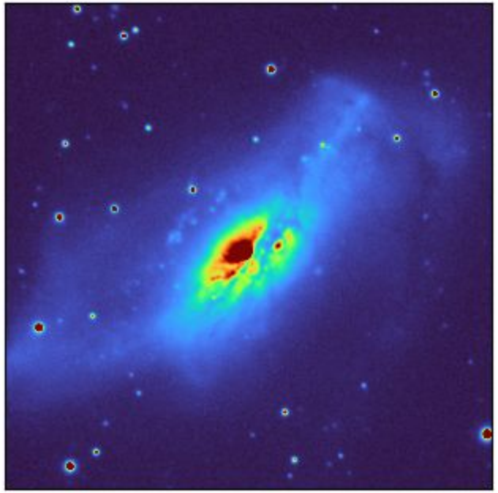
➔ *Check out talks from L. Pantoni, A. Nersesian, S. Katsioli*

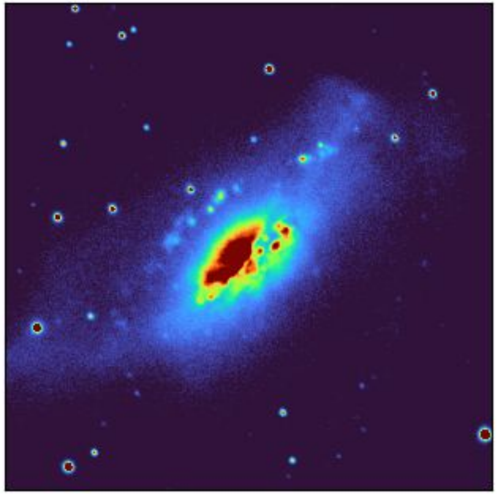
Preliminary results, soon to be published in Ejlali+2023.

NGC2146

- Spiral galaxy, inclined **57°**
- Distance **18 Mpc**
- Apparent size **6'x3.4'**
- Physical size equivalent to a **6"** pixel **~500pc**
- Starburst galaxy, **SFR=34±11 $M_{\odot}$/yr**

(Nersesian+2019)

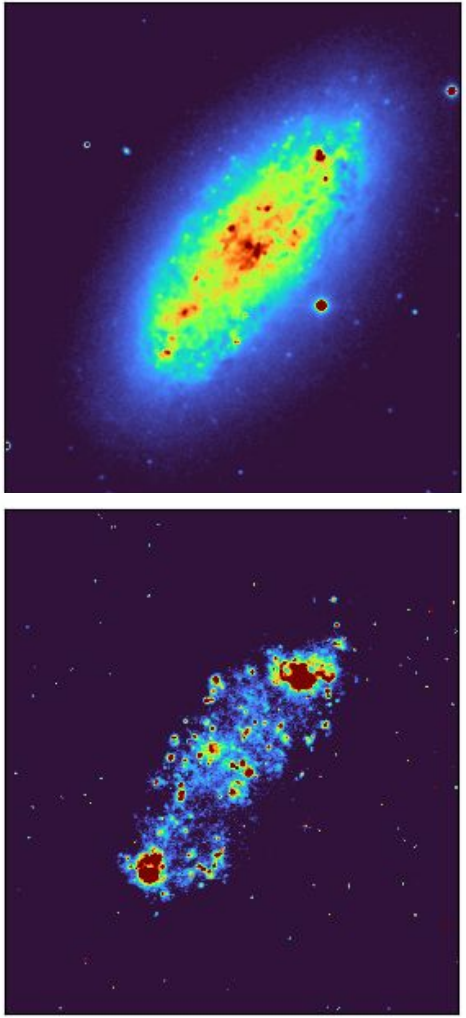




NGC2146 observed with WIYN0.9m telescope (Cheng+1997)
Red(top) and Hα (bottom)

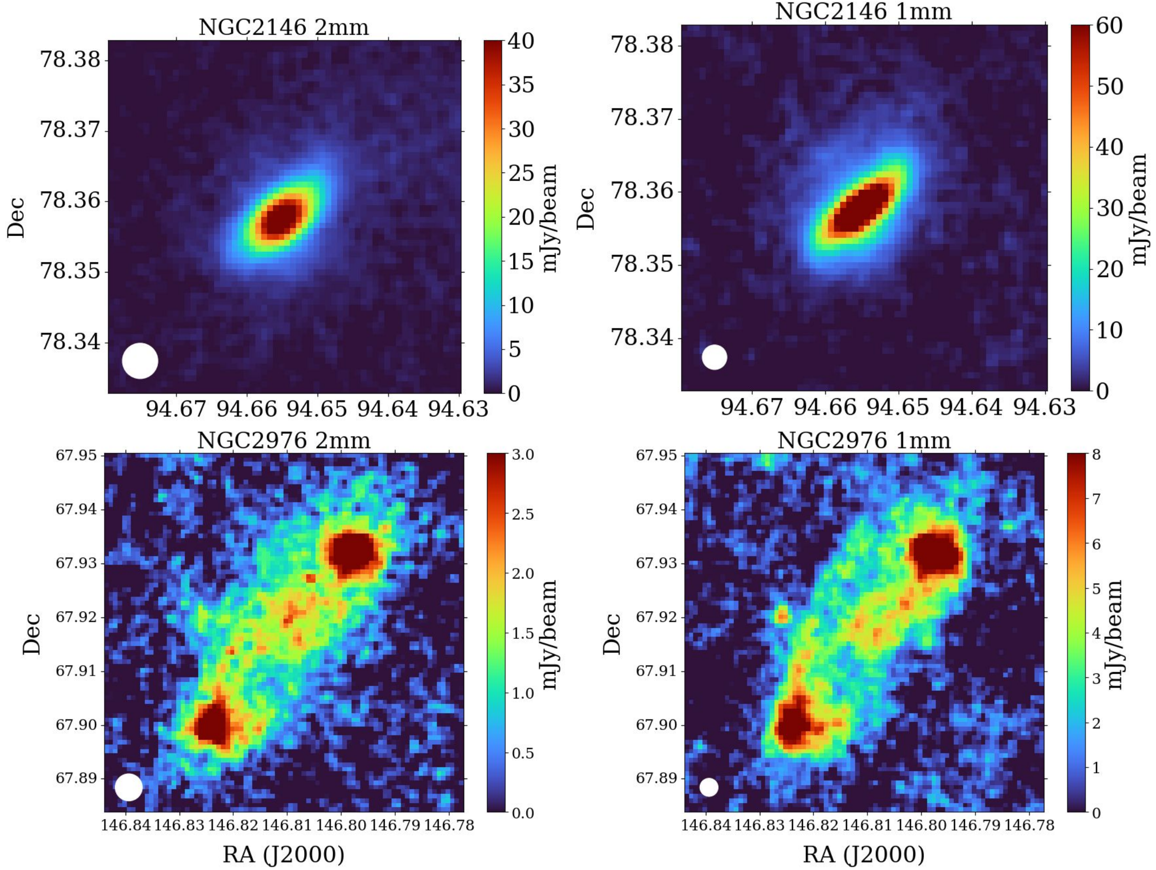
NGC2976

- Dwarf galaxy, inclined 65°
- Distance 3.5 Mpc
- Apparent size 5.9’x2.7’
- Physical size equivalent to a 6” pixel ~100pc
- Star forming galaxy, SFR=0.13±0.02 $M_{\odot}$/yr (Nersesian+2019)
- Metallicity 12+log(O/H)=8.39±0.03



NGC2976, in filters Red (top) observed with (Dale+2009), and Hα (bottom) observed with KPNO2.1m (SINGS2007)

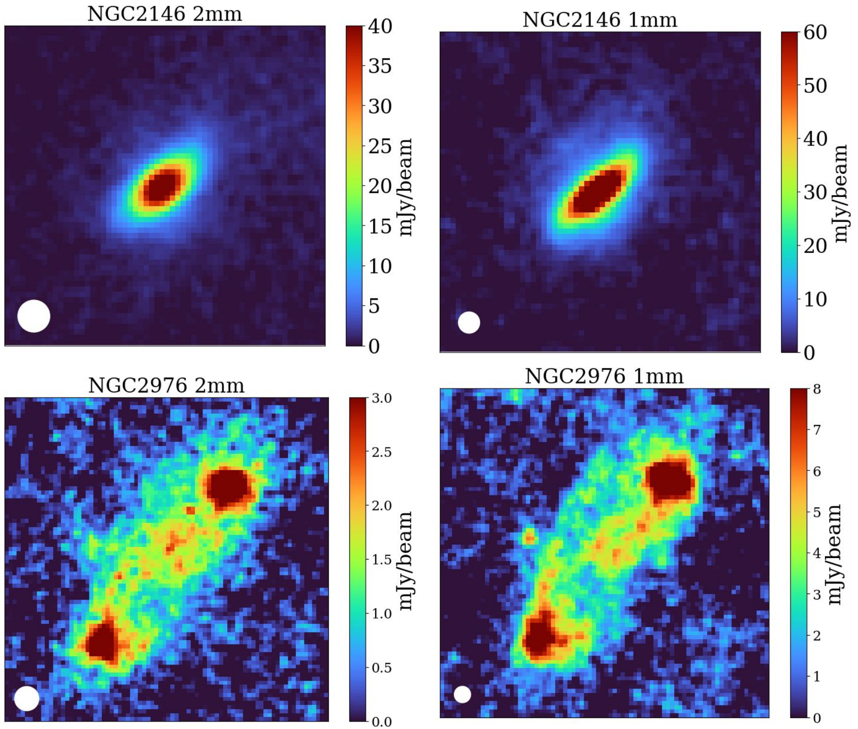
NIKA2 observations



NIKA2 observations of NGC2146 (top) and NGC2976 (bottom) at 1mm (right) and 2mm (left)

NIKA2 observations

- Observed time:
  - NGC2146: 5.0 hours
  - NGC2976: 5.3 hours
- Resolution: (Perotto+2020)
  - At **1mm**: 12 arcsec
  - At **2mm**: 18 arcsec
- Physical scale of 18” beam:
  - NGC2146: **1.6 kpc**
  - NGC2976: **0.3 kpc**
- Reduced with *Scanam_NIKA* pipeline by Helene Roussel

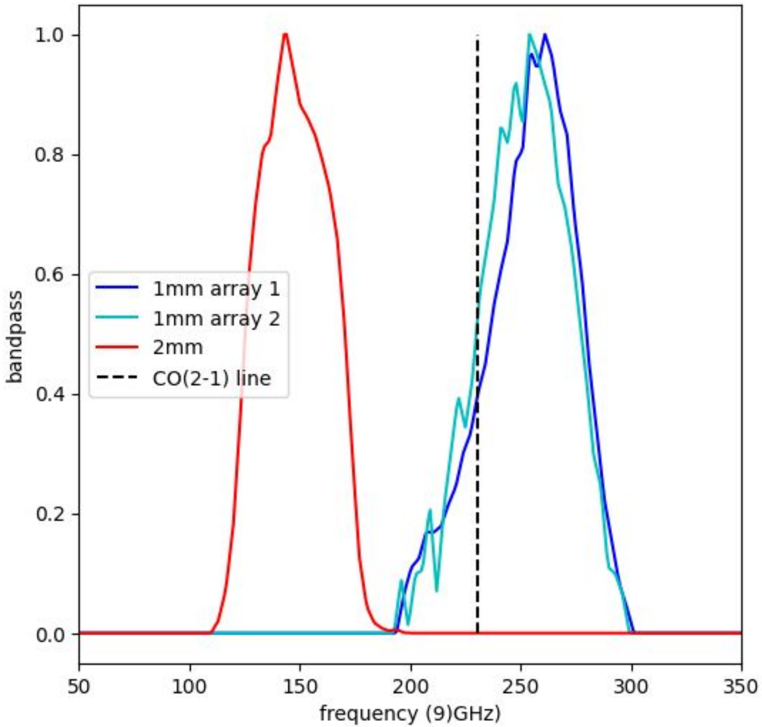


	Integrated flux (mJy)		rms noise (mJy/beam)	
	1mm	2mm	1mm	2mm
NGC2146	**529**	**131**	**0.9**	**0.24**
NGC2976	**419**	**65**	**0.8**	**0.23**

CO contamination

Emission in millimeter consists of:

1. Continuum thermal emission from dust
2. Continuum thermale free-free emission
3. Continuum non-thermal synchrotron emission
4. Line emission from CO(2-1)



- CO(2-1) data from HERACLES survey
  (Leroy+2009)

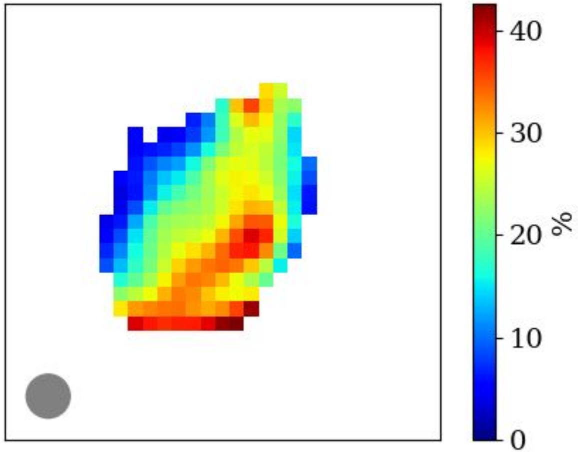
CO contamination

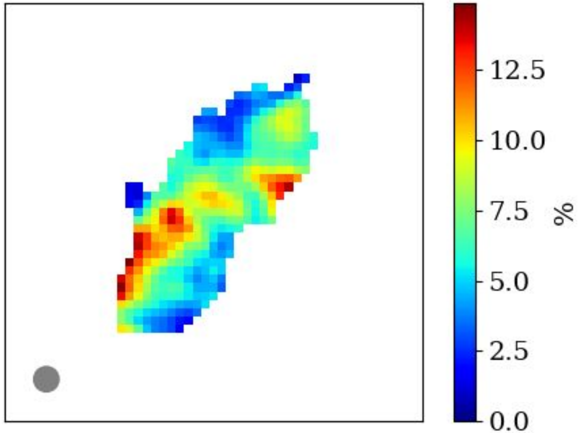
Emission in millimeter consists of:

1. Continuum thermal emission from dust
2. Continuum thermale free-free emission
3. Continuum non-thermal synchrotron emission
4. Line emission from CO(2-1) ✓

- Contribution of CO in integrated flux:
  - NGC2146: **26%**
  - NGC2976: **7%**

Percentage of contribution of CO line emission in NIKA2 1mm observed maps in NGC2146 (top) and NGC2976 (bottom)





Analytical model

Emission in millimeter consists of:

1. Continuum thermal emission from dust

   MBB model $\kappa_0(\nu/\nu_0)^\beta$ M/D^2 $B(\nu,T)$

2. Continuum thermale free-free emission

   $A_1(\nu/\nu_0)^{-0.1}$

3. Continuum non-thermal synchrotron emission

   $A_2(\nu/\nu_0)^{-\alpha}$

4. Line emission from CO(2-1) : subtracted ✓

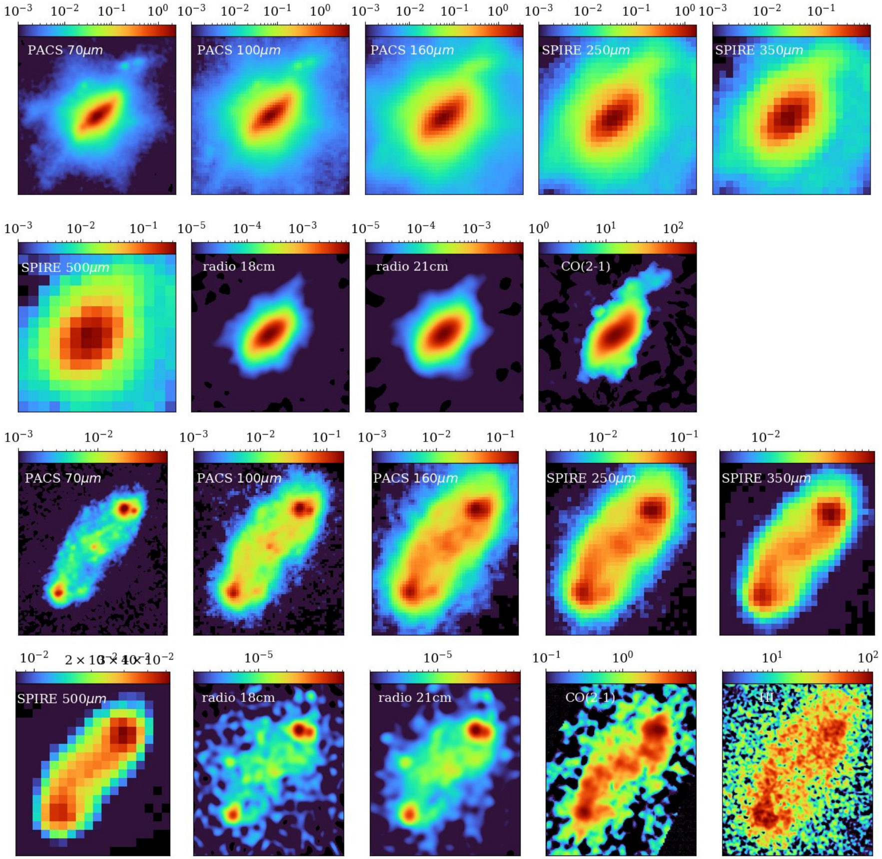
Analytical model

$$S_\nu = \kappa_0(\nu/\nu_0)^\beta M/D^2 B(\nu,T) + A_1(\nu/\nu_0)^{-0.1} + A_2(\nu/\nu_0)^{-\alpha}$$

6 free parameters:

1. Dust mass M_{dust},
2. Dust temperature T_{dust},
3. Dust emissivity index β,
4. Contribution of free-free emission A_1 or $f_{th}=A_1/S(21cm)$,
5. Contribution of synchrotron emission A_2,
6. Synchrotron spectral index α_{syn}

Complementary data



telescope	wavelength
Herschel-PACS	70-100-160 µm
Herschel-SPIRE	250-350-500 µm
Planck	1.38 mm
NIKA2	1.15-2 mm
Effelsberg	6.2 cm
WSRT	18-21 cm

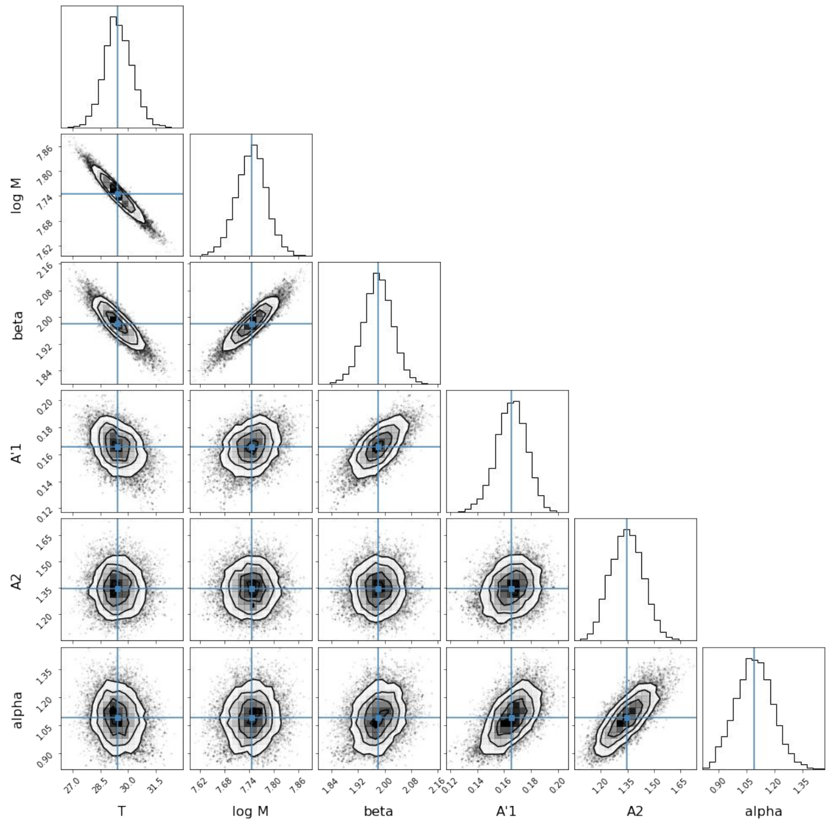
Fitting process

- Fitting method: Bayesian MCMC
- We account for transmission functions of each instrument.

Step 1: **Global SED modelling**

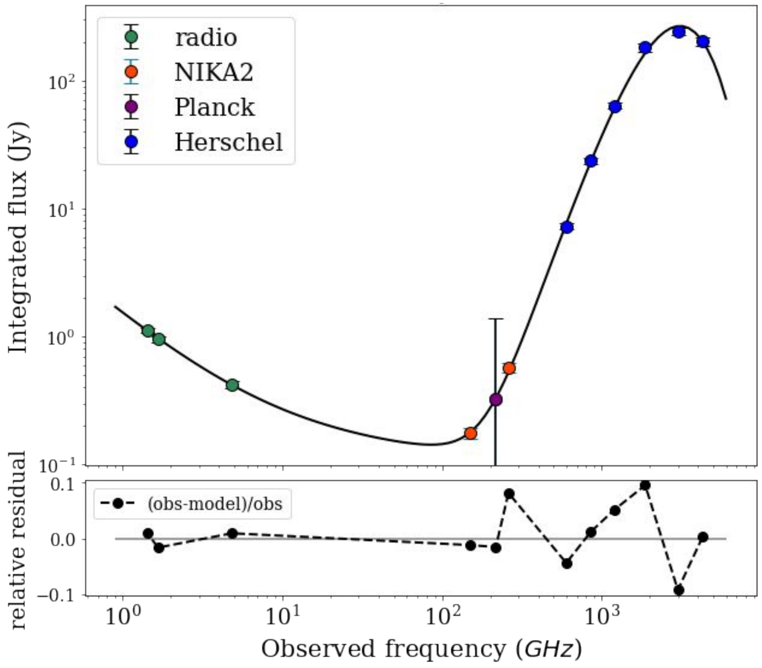
- Integration radius:
    - NGC2146: **260 arcsec**
    - NGC2976: **220 arcsec**

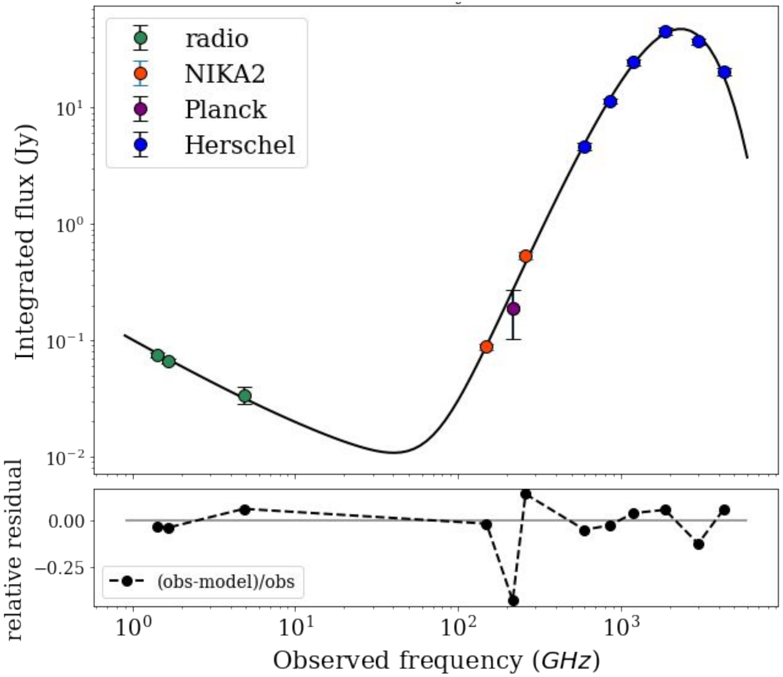
Step 2: **Resolved SED modelling**



Global SED modelling

SED parameter	NGC2146	NGC2976
T (K)	$30.98^{+1.21}_{-0.19}$	$26.69^{+0.62}_{-0.64}$
M ($M_{\odot}$)	$4.88^{+0.52}_{-0.52} \times 10^7$	$1.02^{+0.08}_{-0.07} \times 10^6$
β	$1.83^{+0.10}_{-0.09}$	$1.27^{+0.06}_{-0.05}$
A'_1	$0.15^{+0.02}_{-0.03}$	$0.007^{+0.01}_{-0.01}$
A_2	$1.35^{+0.08}_{-0.08}$	$0.092^{+0.01}_{-0.01}$
α_{nth}	$1.06^{+0.12}_{-0.11}$	$0.82^{+0.39}_{-0.22}$





👈 Modelled global SEDs of NGC2146 (left) and NGC2976 (right)

Step 1: **Global SED modelling** ✓

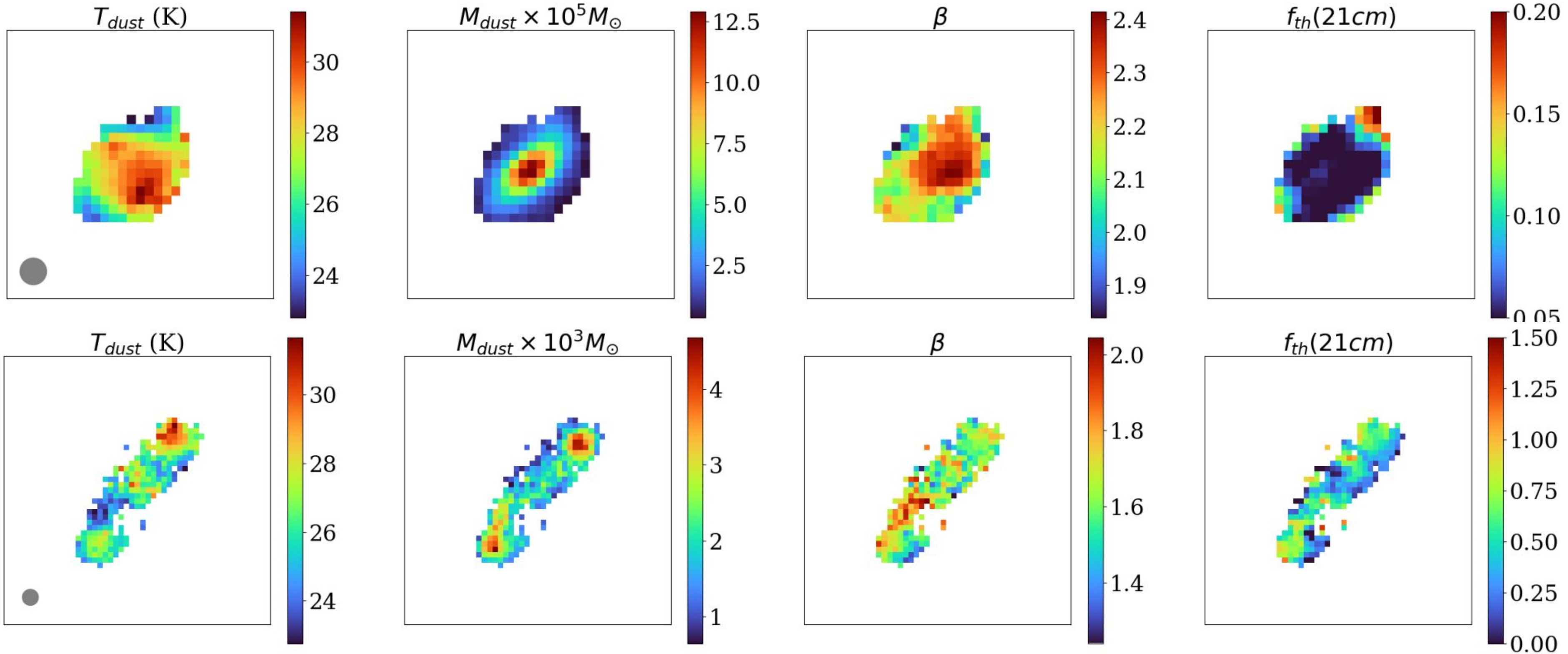
Step 2: **Resolved SED modelling**

- Resolution 18 arcsec
  - We discard SPIRE **350** and **500** μm and Planck **1.3mm**
- All maps were convolved to same resolution and geometry.
- We fix α_{syn}
  - 5 free parameters

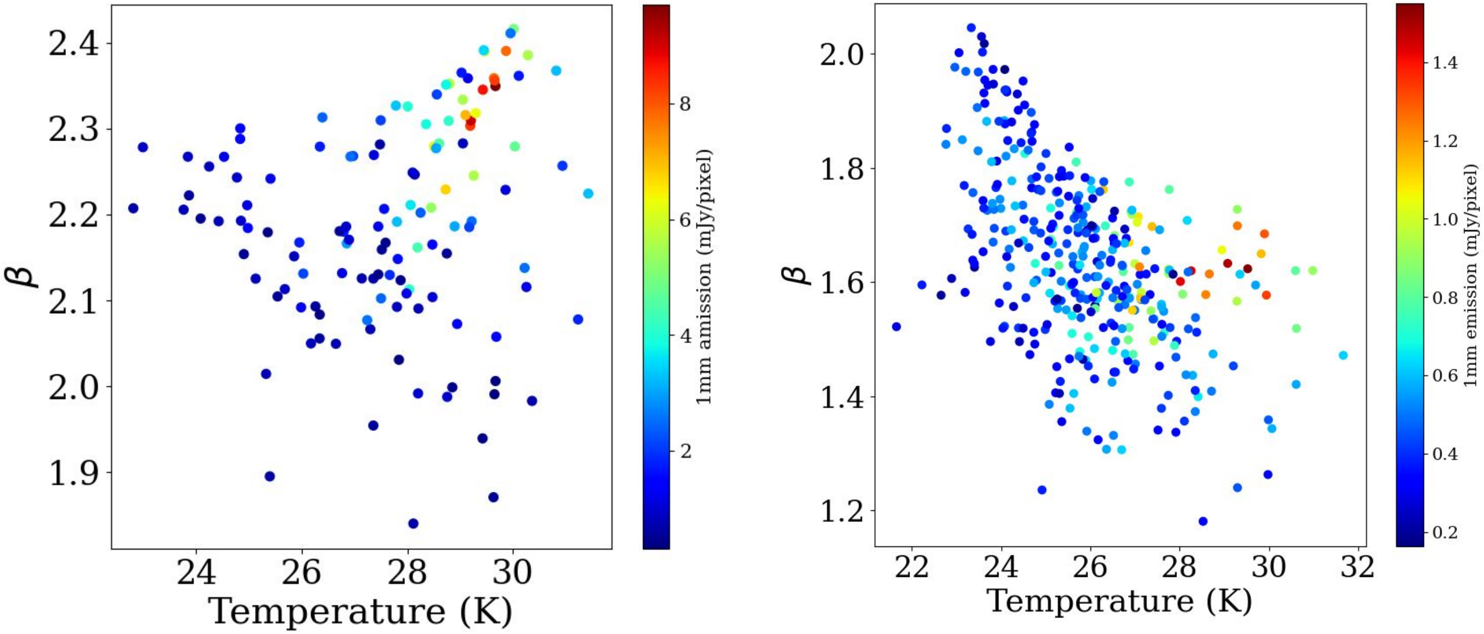
    M_{dust} , T_{dust} , β , $f_{th}=A_1/S(21cm)$

Resolved SED modelling

Modelled parameters for NGC2146 (top) and NGC2976 (bottom) 👇



Dust temperature vs. emissivity index



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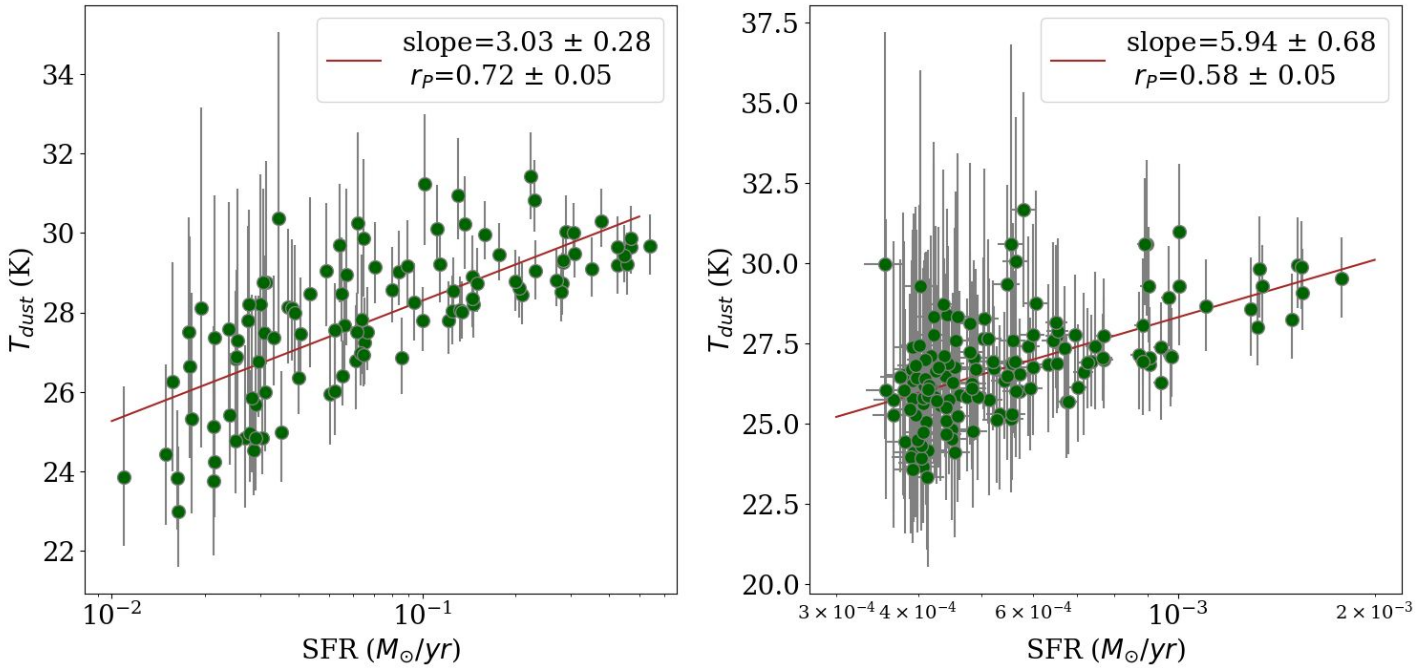
T-β relation for NGC2146 (left) and NGC2976 (right)

Dust temperature vs. SFR

- SFR computed from Spitzer MIPS 24μm



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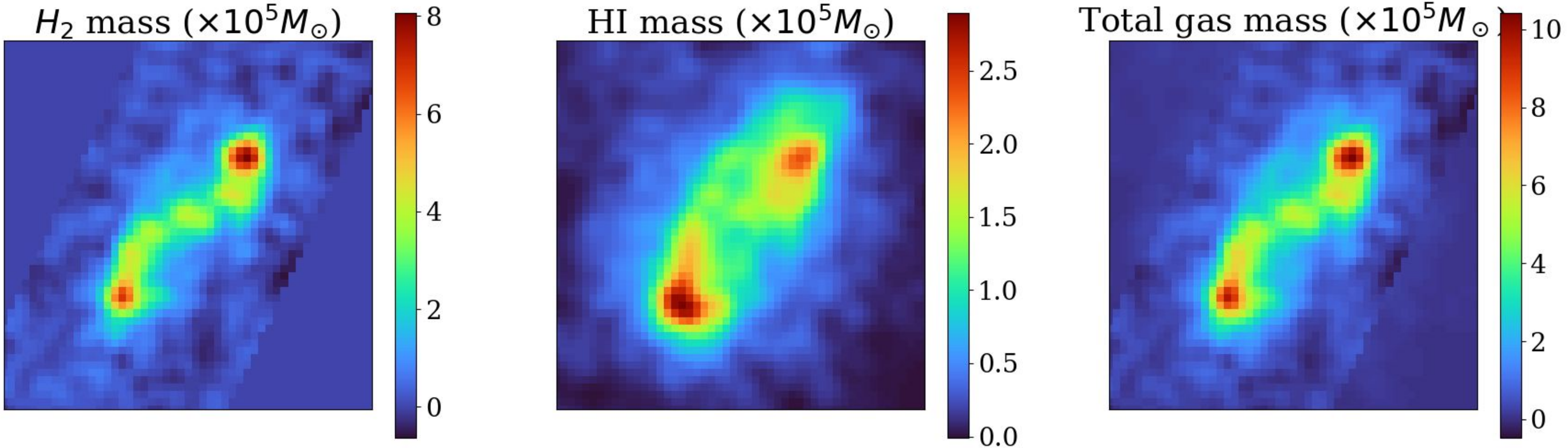
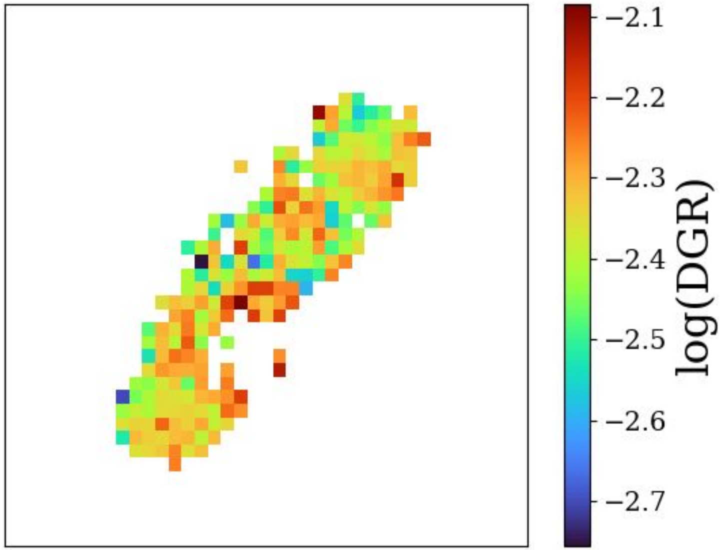
T-SFR relation for NGC2146 (left) and NGC2976 (right)

Gas in NGC2976

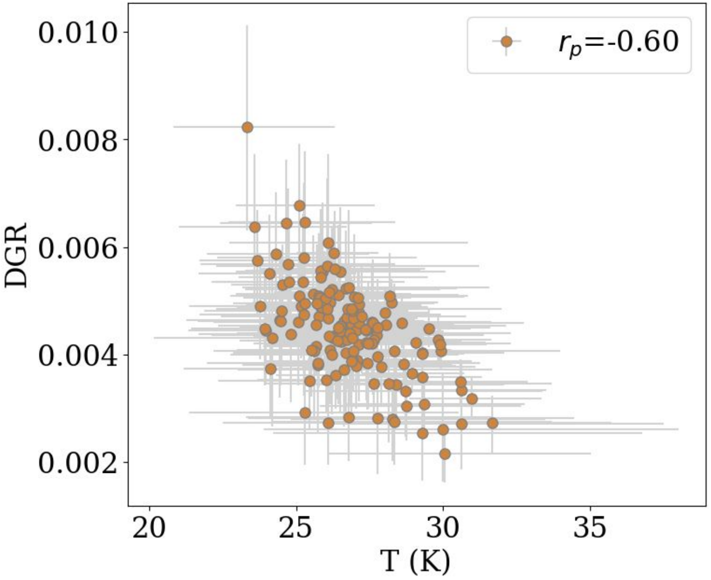
- Atomic gas: THINGS survey (Walter+2008)
- Molecular gas: from CO data (Leroy+2008)



Dust-to-gas ratio

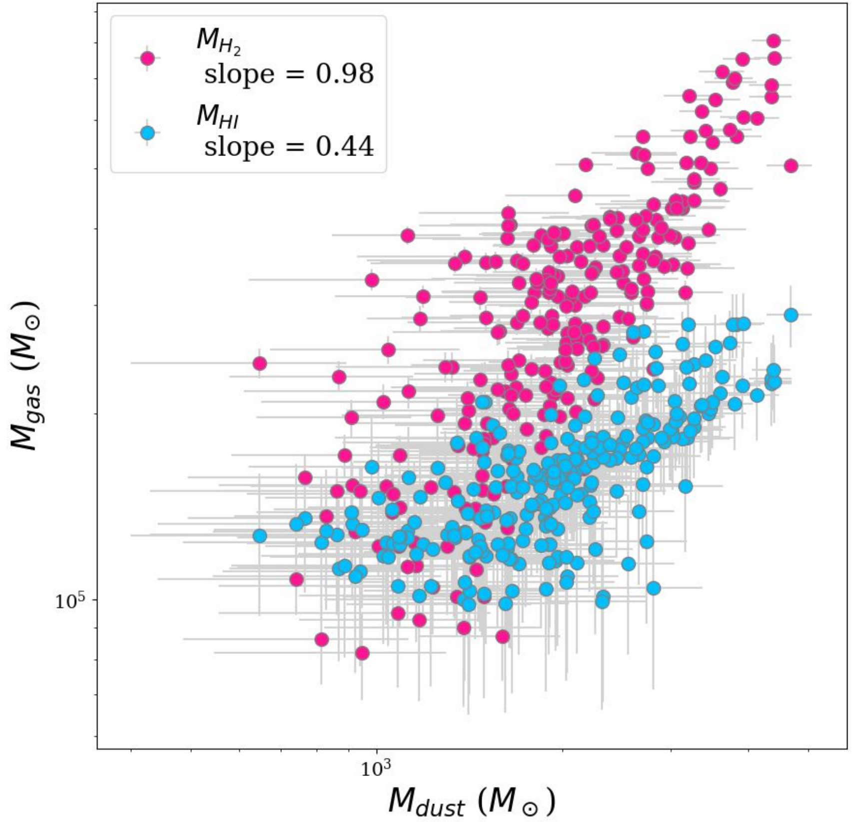


👉 log(DGR) in NGC2976



👈 DGR-T relation NGC2976

Role of dust in formation of molecular gas



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Relation of different gas components with dust

Role of dust in formation of molecular gas

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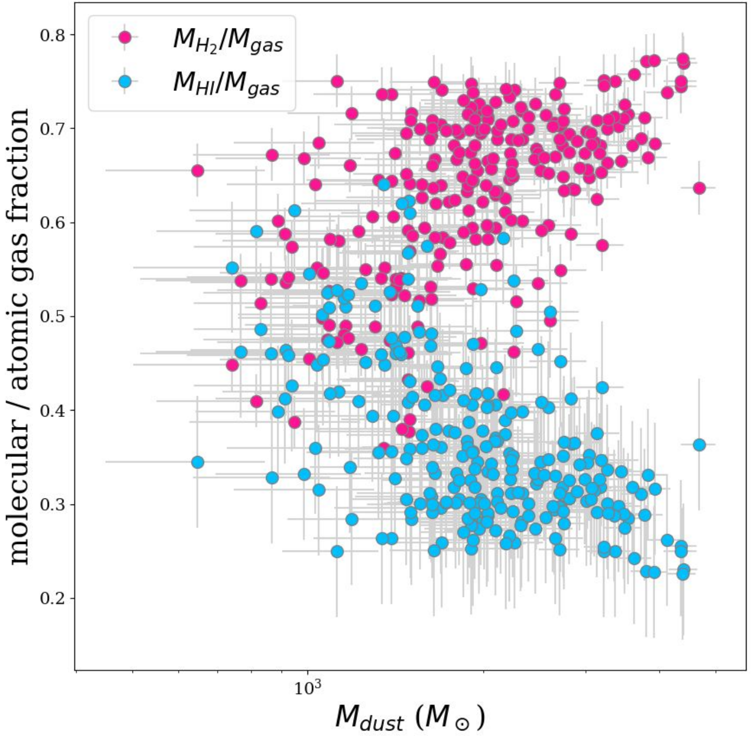
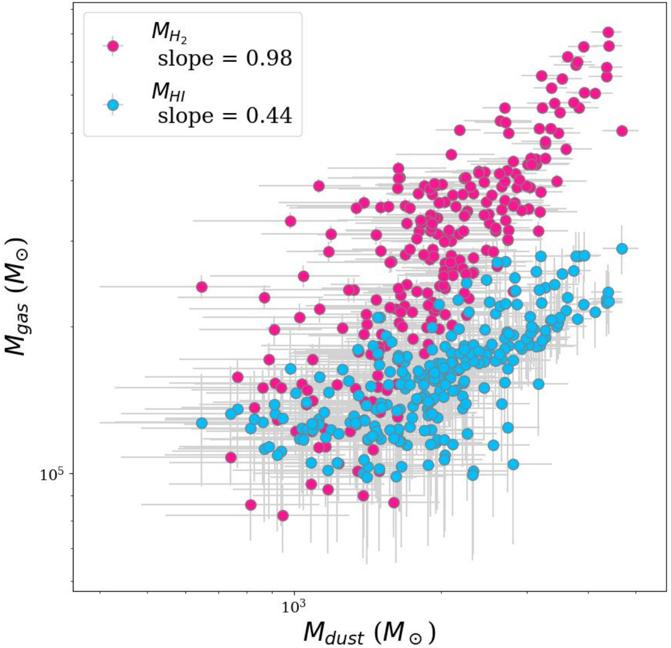
Relation of fraction of different gas components with dust





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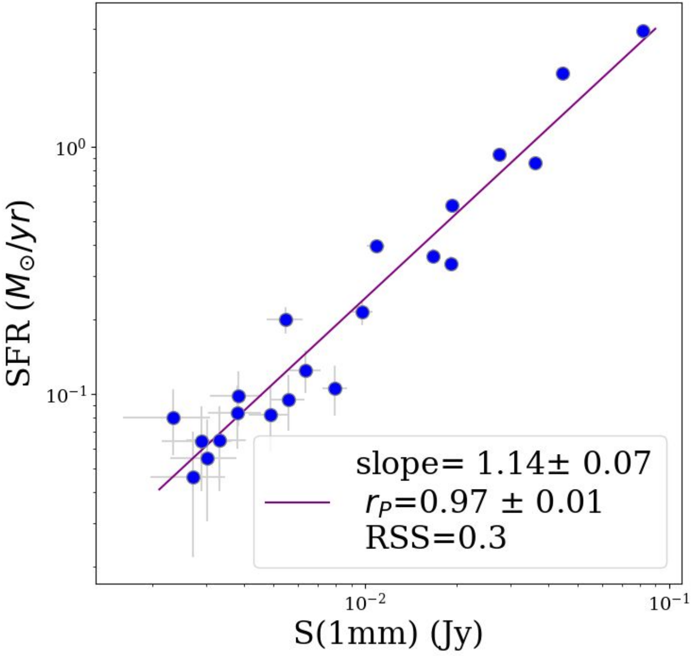
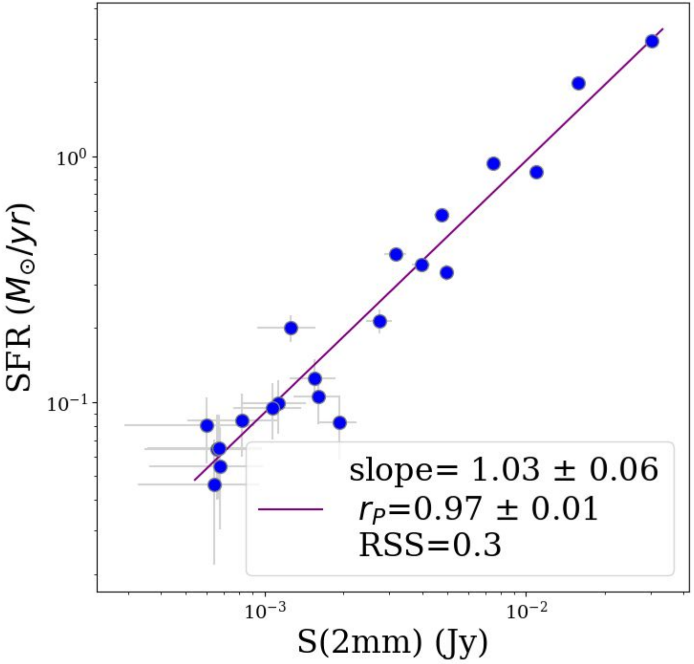
Relation of different gas components with dust

NIKA2 as SFR calibrator

Strong correlation of emission at 1 and 2 mm with SFR for NGC2146.
Maps smoothed to beam size pixels, to avoid internal correlation between pixels.





NIKA2 as SFR calibrator

Strong correlation of emission at 1 and 2 mm with SFR for NGC2976.
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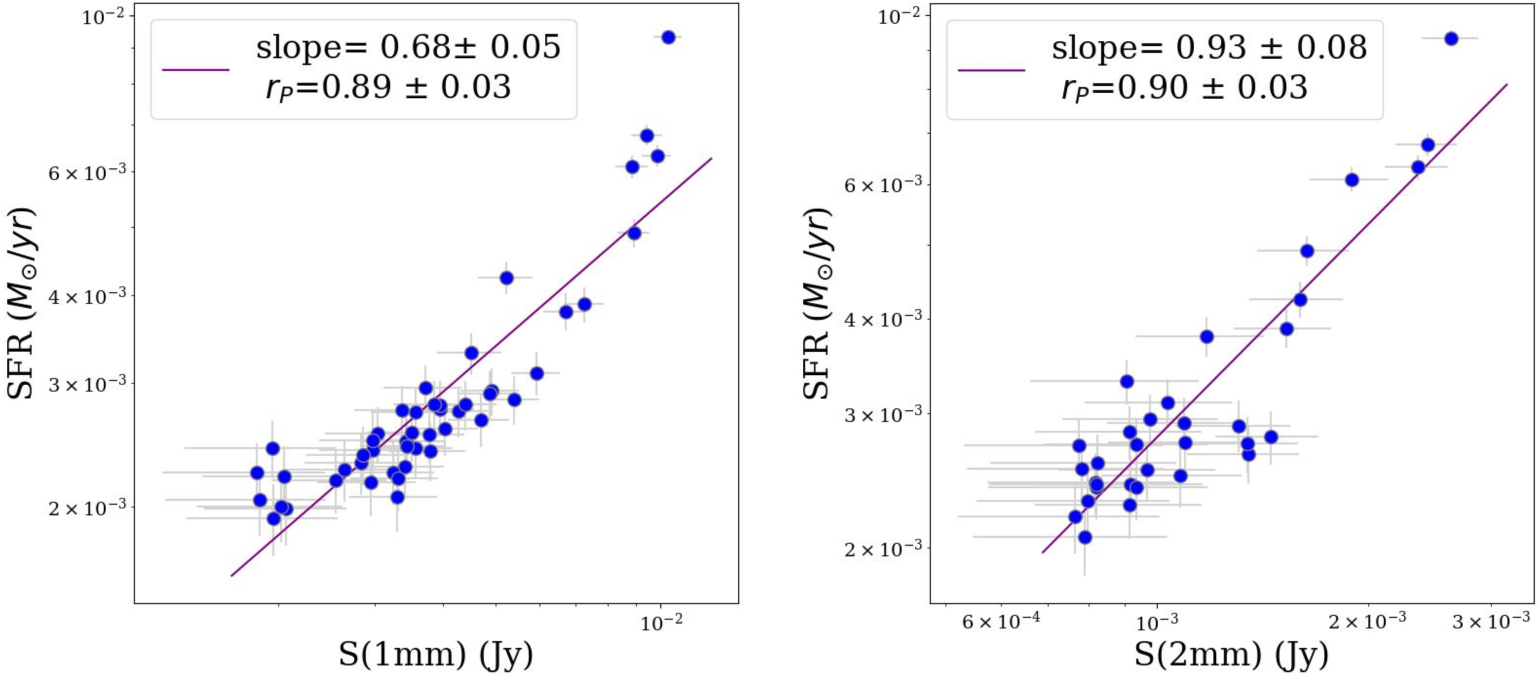
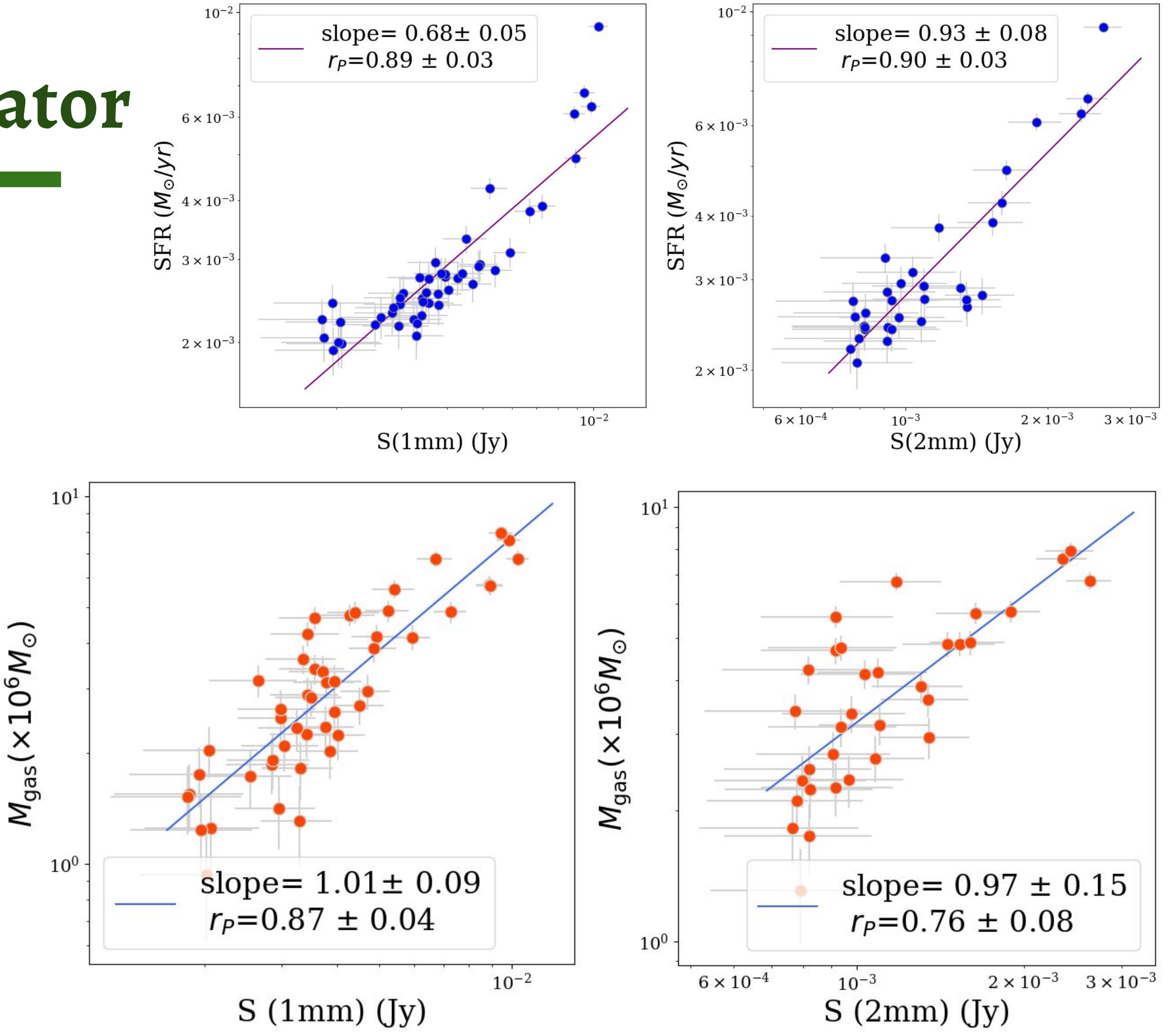


NIKA2 as gas calibrator

Strong correlation of emission at 1 and 2 mm with total gas mass.

Better linearity in relation of gas: correlation of NIKA2 vs. SFR is rooted in correlation of NIKA2 vs. gas.



Relation of emission of NGC2976 at 1 and 2 mm with SFR (top) and gas mass (bottom)

Summary of important points

- Up to **40%** of emission (per pixel) at **1mm** is caused by CO, when observing nearby galaxies.
- Dust temperature is highly correlated with SFR, showing role of energetic photons in heating of dust.
- DGR is inversely correlated with dust temperature, showing the role of energetic radiation field in destruction of dust.
- In dust-rich regions, fraction of molecular gas is more than atomic gas.
- NIKA2 observation at millimeter wavelengths shows strong correlation with SFR, hence can be used as a SFR calibrator.
- In NGC2976, we see strong linear correlation between emission at **1** and **2mm** and total gas mass, so NIKA2 can be used as a calibrator of total gas mass as well.

Thank you