# The Long-Wavelength Dust Properties of Nearby Galaxies, Probed by NIKA2

Frédéric GALLIANO[1]
& the IMEGIN / SEINFELD / WIDENING collaboration

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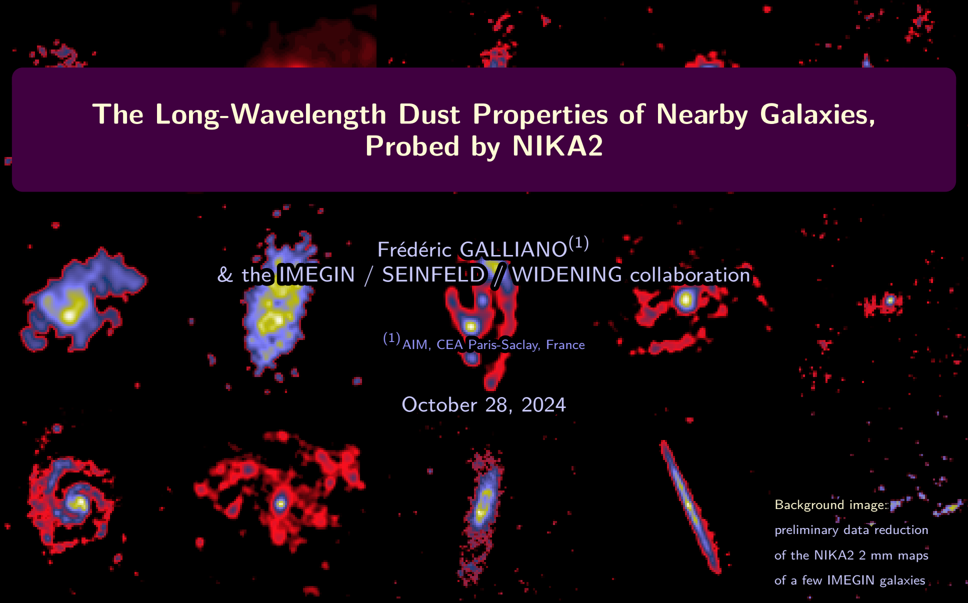

Background image: preliminary data reduction of the NIKA2 2 mm maps of a few IMEGIN galaxies

# Talk T.O.C.

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   - The importance of the millimeter properties of dust grains
   - Studies of the submmillimeter excess
   - The challenging nature of these observations

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   - The SEINFELD NIKA2 program
   - Multiwavelength, spatially-resolved SED modeling
   - Dependence of the submillimeter excess on the physical conditions

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   - Take-away points
   - Shameless ads
   - References

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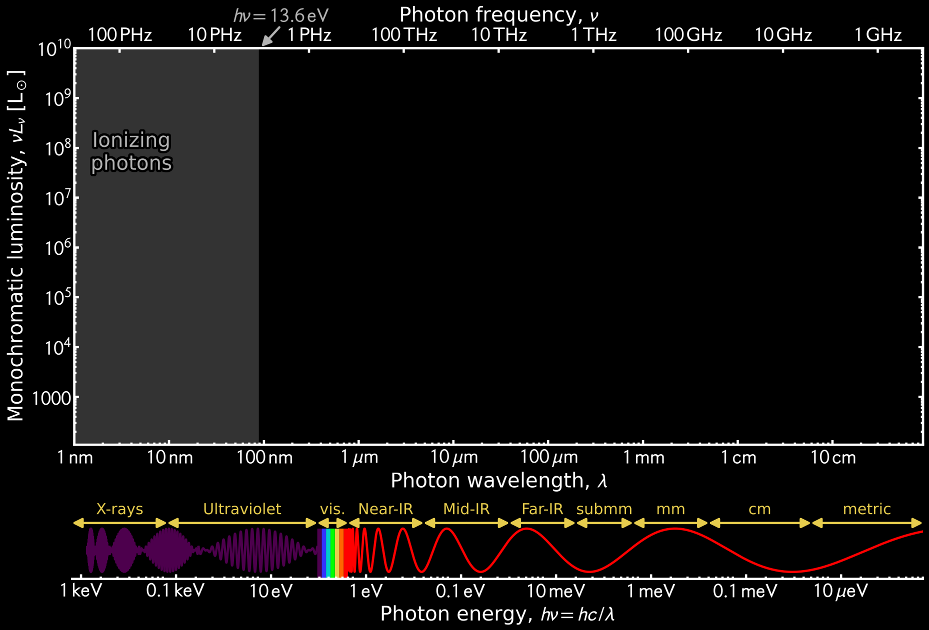
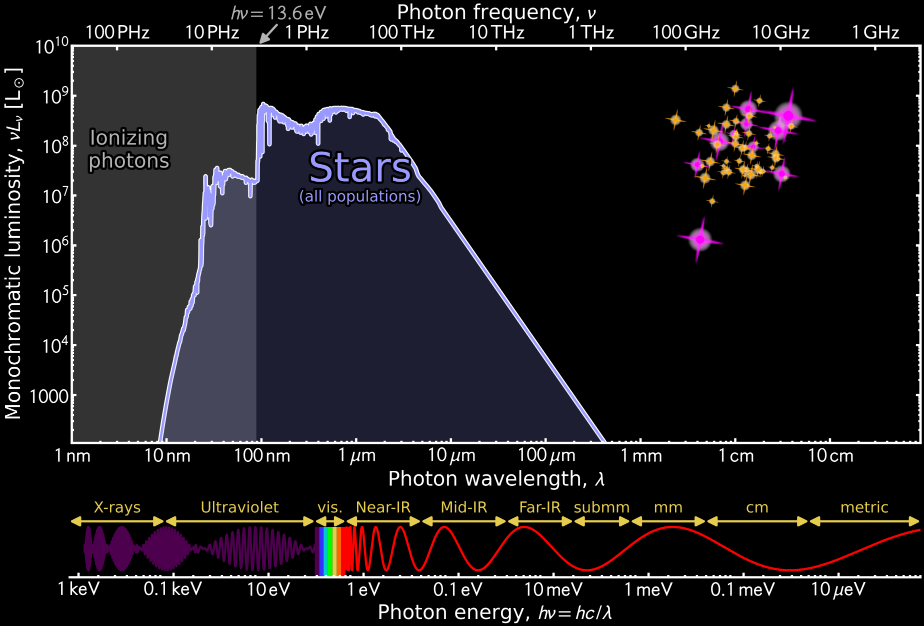

$h\nu = 13.6\,\mathrm{eV}$
Photon frequency, $\nu$
100 PHz
10 PHz
1 PHz
100 THz
10 THz
1 THz
100 GHz
10 GHz
1 GHz
Monochromatic luminosity, $\nu L_\nu$ [$L_\odot$]
$10^{10}$
$10^9$
$10^8$
$10^7$
$10^6$
$10^5$
$10^4$
1000
Ionizing photons
1 nm
10 nm
100 nm
1 $\mu$m
10 $\mu$m
100 $\mu$m
1 mm
1 cm
10 cm
Photon wavelength, $\lambda$
X-rays
Ultraviolet
vis.
Near-IR
Mid-IR
Far-IR
submm
mm
cm
metric
1 keV
0.1 keV
10 eV
1 eV
0.1 eV
10 meV
1 meV
0.1 meV
10 $\mu$eV
Photon energy, $h\nu = hc/\lambda$



$h\nu = 13.6\,\mathrm{eV}$
Photon frequency, $\nu$
100 PHz
10 PHz
1 PHz
100 THz
10 THz
1 THz
100 GHz
10 GHz
1 GHz
Monochromatic luminosity, $\nu L_\nu$ [$L_\odot$]
$10^{10}$
$10^{9}$
$10^{8}$
$10^{7}$
$10^{6}$
$10^{5}$
$10^{4}$
1000
Ionizing photons
Stars
(all populations)
1 nm
10 nm
100 nm
1 $\mu$m
10 $\mu$m
100 $\mu$m
1 mm
1 cm
10 cm
Photon wavelength, $\lambda$
X-rays
Ultraviolet
vis.
Near-IR
Mid-IR
Far-IR
submm
mm
cm
metric
1 keV
0.1 keV
10 eV
1 eV
0.1 eV
10 meV
1 meV
0.1 meV
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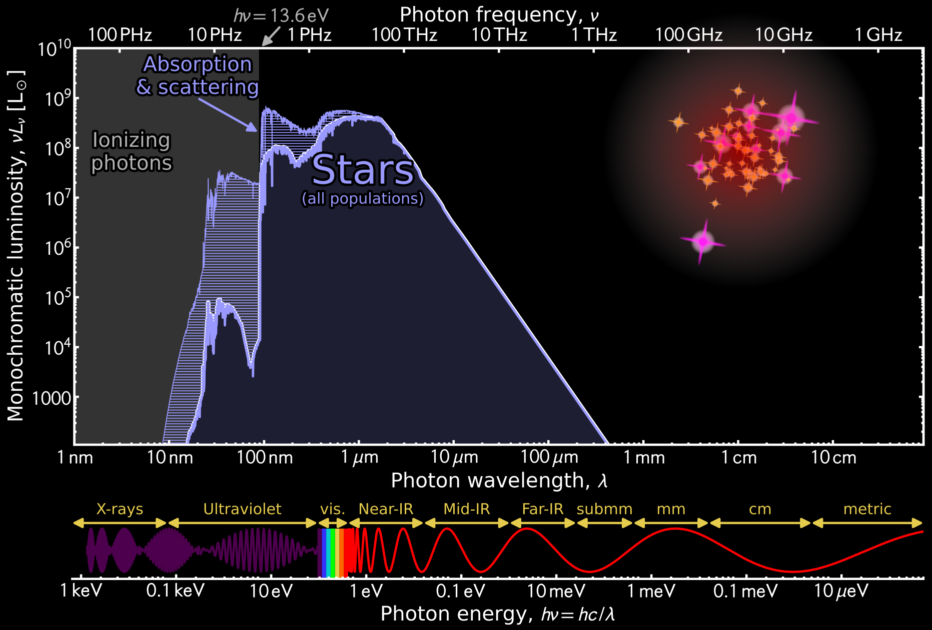
Photon energy, $h\nu = hc/\lambda$



$h\nu = 13.6\,\mathrm{eV}$
Photon frequency, $\nu$
100 PHz
10 PHz
1 PHz
100 THz
10 THz
1 THz
100 GHz
10 GHz
1 GHz
Monochromatic luminosity, $\nu L_\nu$ [$L_\odot$]
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$10^8$
$10^7$
$10^6$
$10^5$
$10^4$
1000
Absorption & scattering
Ionizing photons
Stars
(all populations)
1 nm
10 nm
100 nm
1 μm
10 μm
100 μm
1 mm
1 cm
10 cm
Photon wavelength, $\lambda$
X-rays
Ultraviolet
vis.
Near-IR
Mid-IR
Far-IR
submm
mm
cm
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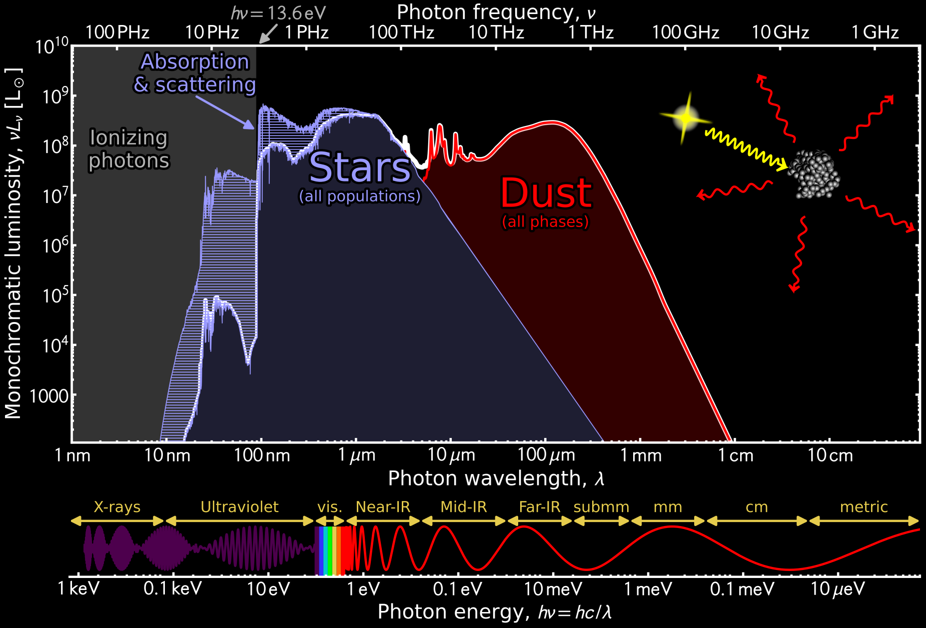
0.1 keV
10 eV
1 eV
0.1 eV
10 meV
1 meV
0.1 meV
10 μeV
Photon energy, $h\nu = hc/\lambda$



$h\nu = 13.6\,\mathrm{eV}$
Photon frequency, $\nu$
100 PHz
10 PHz
1 PHz
100 THz
10 THz
1 THz
100 GHz
10 GHz
1 GHz
Absorption & scattering
Ionizing photons
Stars (all populations)
Dust (all phases)
Monochromatic luminosity, $\nu L_\nu$ [$L_\odot$]
$10^{10}$
$10^{9}$
$10^{8}$
$10^{7}$
$10^{6}$
$10^{5}$
$10^{4}$
1000
1 nm
10 nm
100 nm
1 $\mu$m
10 $\mu$m
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1 mm
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Photon wavelength, $\lambda$
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Near-IR
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1 eV
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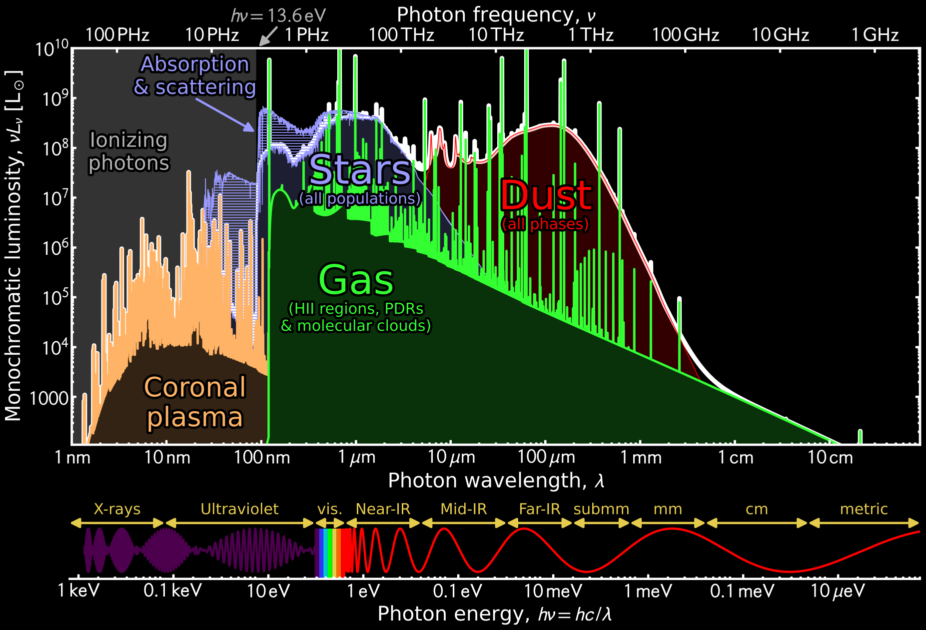
1 meV
0.1 meV
10 $\mu$eV
Photon energy, $h\nu = hc/\lambda$



Photon frequency, ν
hν = 13.6 eV
100 PHz
10 PHz
1 PHz
100 THz
10 THz
1 THz
100 GHz
10 GHz
1 GHz
Monochromatic luminosity, νLν [L⊙]
10^10
10^9
10^8
10^7
10^6
10^5
10^4
1000
Absorption & scattering
Ionizing photons
Stars
(all populations)
Dust
(all phases)
Gas
(HII regions, PDRs & molecular clouds)
Coronal plasma
1 nm
10 nm
100 nm
1 μm
10 μm
100 μm
1 mm
1 cm
10 cm
Photon wavelength, λ
X-rays
Ultraviolet
vis.
Near-IR
Mid-IR
Far-IR
submm
mm
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1 keV
0.1 keV
10 eV
1 eV
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1 meV
0.1 meV
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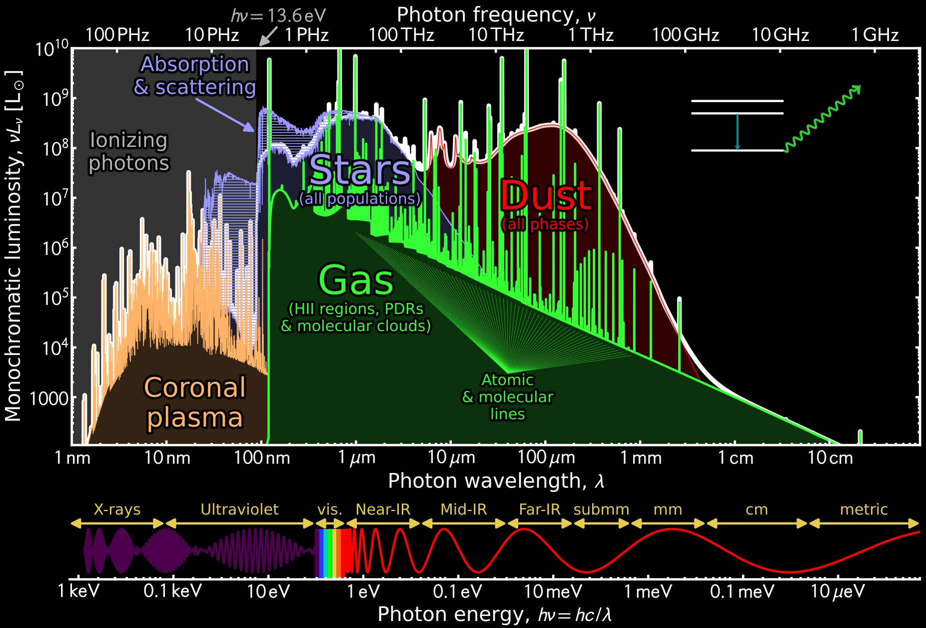
Photon energy, hν = hc/λ



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$h\nu = 13.6\,\mathrm{eV}$
100 PHz
10 PHz
1 PHz
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10 THz
1 THz
100 GHz
10 GHz
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Monochromatic luminosity, $\nu L_\nu$ [$L_\odot$]
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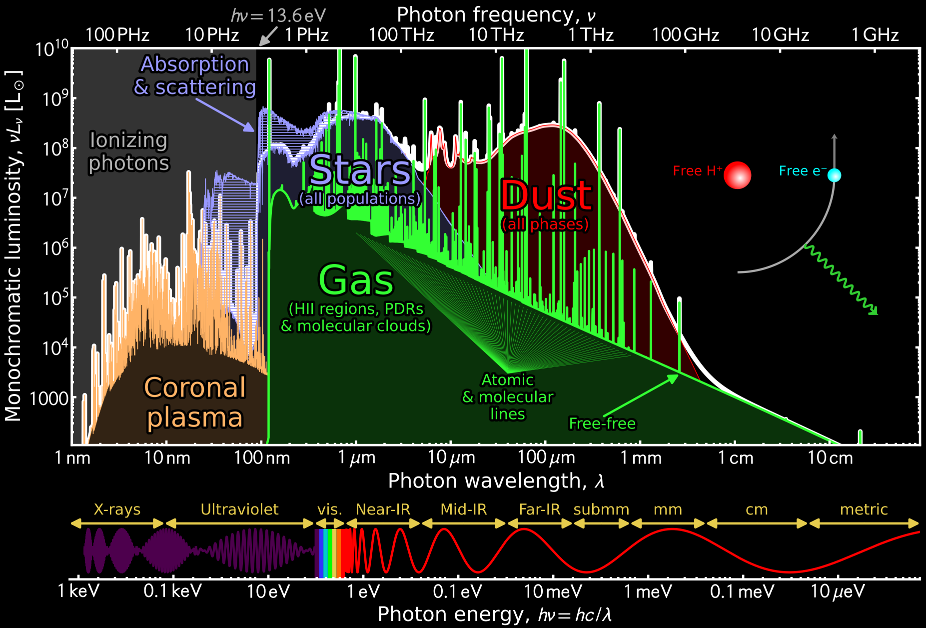
Absorption & scattering
Ionizing photons
Stars (all populations)
Dust (all phases)
Gas (HII regions, PDRs & molecular clouds)
Coronal plasma
Atomic & molecular lines
1 nm
10 nm
100 nm
1 $\mu$m
10 $\mu$m
100 $\mu$m
1 mm
1 cm
10 cm
Photon wavelength, $\lambda$
X-rays
Ultraviolet
vis.
Near-IR
Mid-IR
Far-IR
submm
mm
cm
metric
1 keV
0.1 keV
10 eV
1 eV
0.1 eV
10 meV
1 meV
0.1 meV
10 $\mu$eV
Photon energy, $h\nu = hc/\lambda$



$h\nu = 13.6\,\mathrm{eV}$
Photon frequency, $\nu$
100 PHz
10 PHz
1 PHz
100 THz
10 THz
1 THz
100 GHz
10 GHz
1 GHz
Monochromatic luminosity, $\nu L_\nu$ [$L_\odot$]
$10^{10}$
$10^{9}$
$10^{8}$
$10^{7}$
$10^{6}$
$10^{5}$
$10^{4}$
1000
Absorption & scattering
Ionizing photons
Stars (all populations)
Dust (all phases)
Free H$^+$
Free e$^-$
Gas (HII regions, PDRs & molecular clouds)
Coronal plasma
Atomic & molecular lines
Free-free
1 nm
10 nm
100 nm
1 $\mu$m
10 $\mu$m
100 $\mu$m
1 mm
1 cm
10 cm
Photon wavelength, $\lambda$
X-rays
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1 eV
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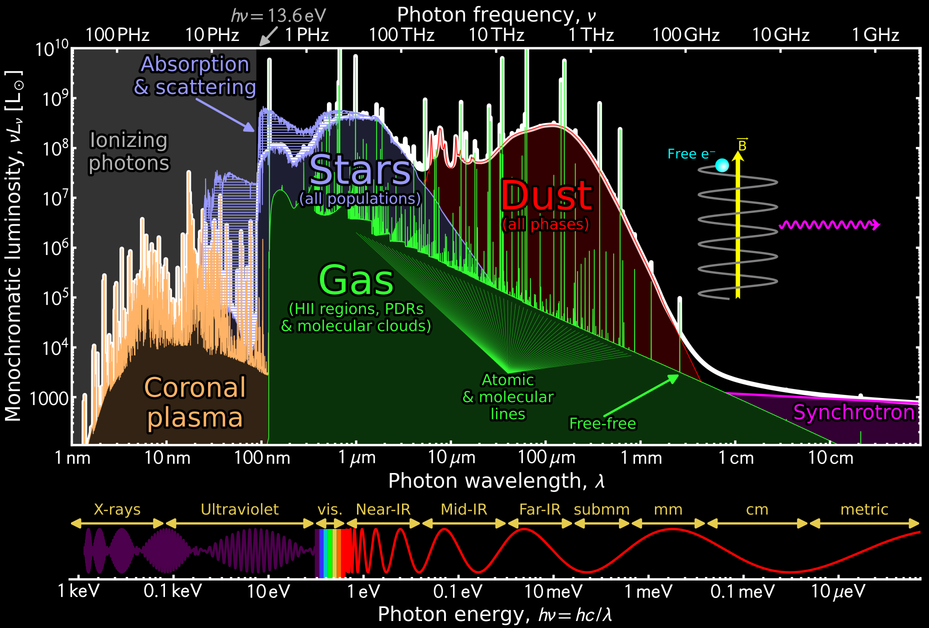
Photon energy, $h\nu = hc/\lambda$



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$h\nu = 13.6\,\mathrm{eV}$
100 PHz
10 PHz
1 PHz
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10 THz
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10 GHz
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Free-free
Synchrotron
Free e⁻
$\vec{B}$
1 nm
10 nm
100 nm
1 $\mu$m
10 $\mu$m
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1 mm
1 cm
10 cm
Photon wavelength, $\lambda$
X-rays
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mm
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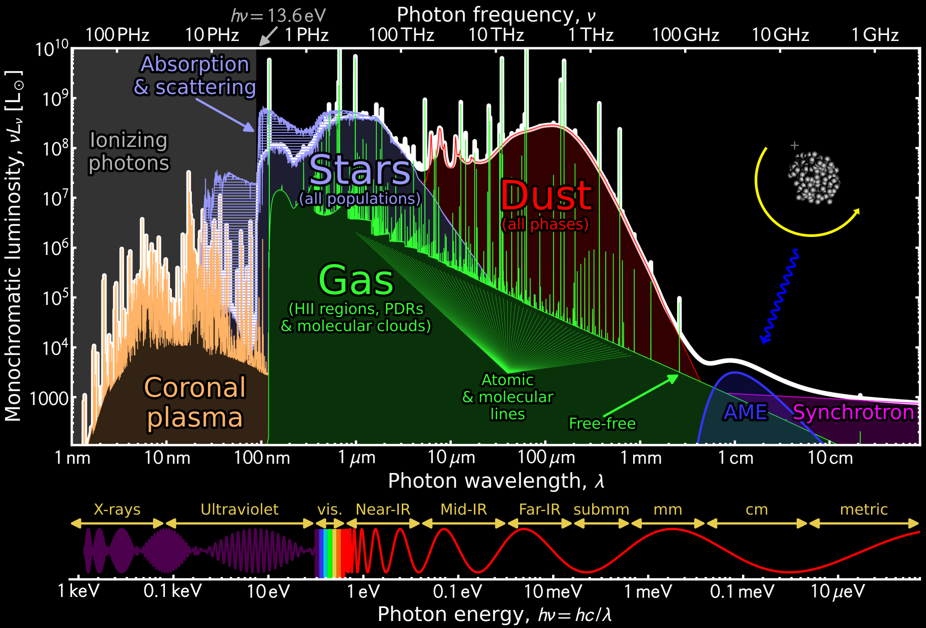
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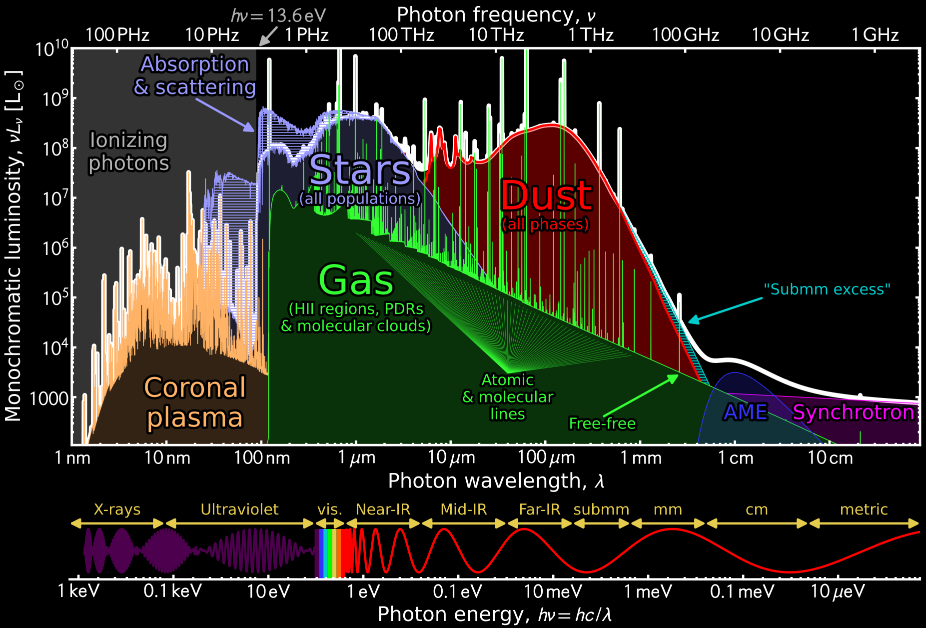

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Gas
(HII regions, PDRs & molecular clouds)
"Submm excess"
Coronal plasma
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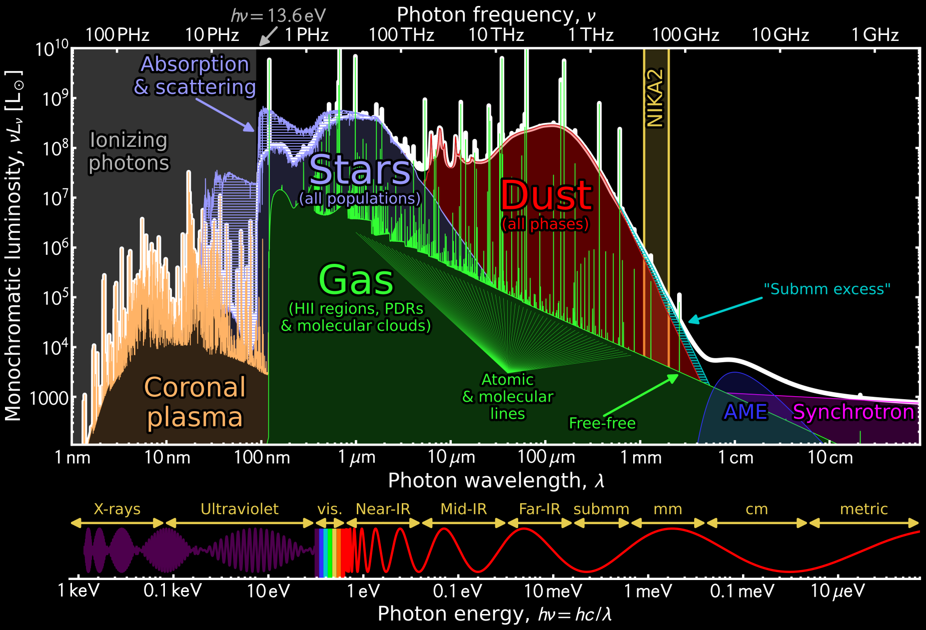
Photon frequency, ν
hν = 13.6 eV
100 PHz
10 PHz
1 PHz
100 THz
10 THz
1 THz
100 GHz
10 GHz
1 GHz
Monochromatic luminosity, νLν [L⊙]
Absorption & scattering
Ionizing photons
Stars (all populations)
Dust (all phases)
NIKA2
Gas (HII regions, PDRs & molecular clouds)
"Submm excess"
Coronal plasma
Atomic & molecular lines
Free-free
AME
Synchrotron
1 nm
10 nm
100 nm
1 μm
10 μm
100 μm
1 mm
1 cm
10 cm
Photon wavelength, λ
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Ultraviolet
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**The mm SED as a dust mass tracer**

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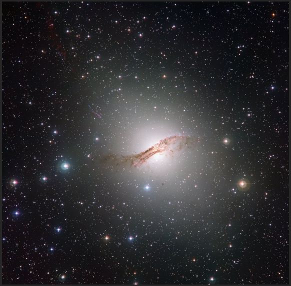

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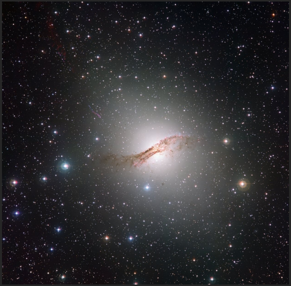
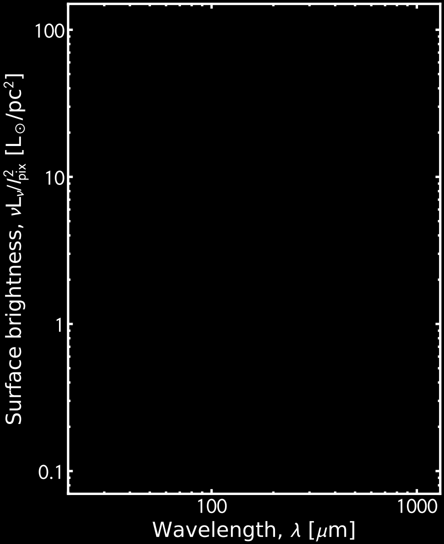


Metallicity: high ($\gtrsim Z_\odot$).
Gas fraction: low ($\lesssim 10\,\%$).
SFR/$M_\star$: low ($\lesssim 0.01$ Gyr$^{-1}$).

LMC (Galliano et al., 2011)



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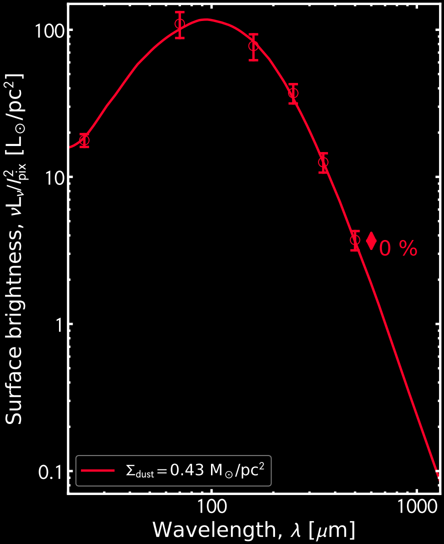

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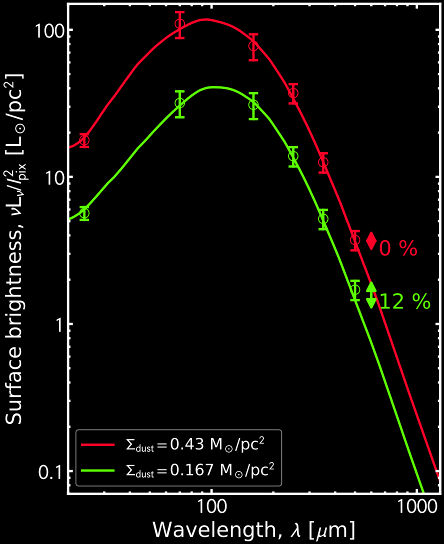

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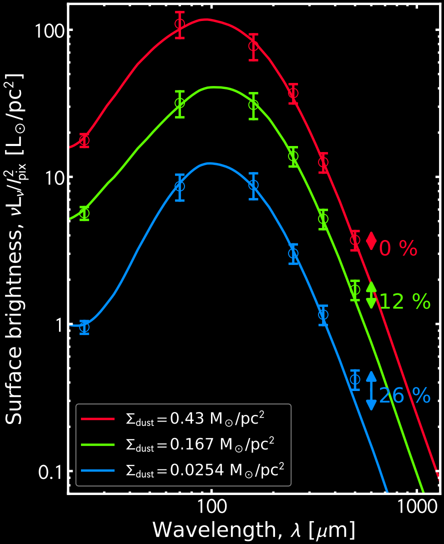

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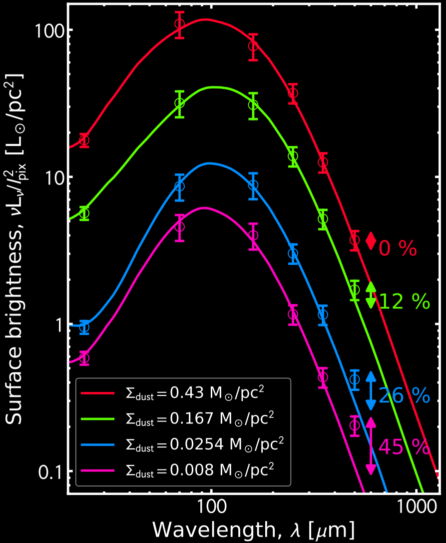

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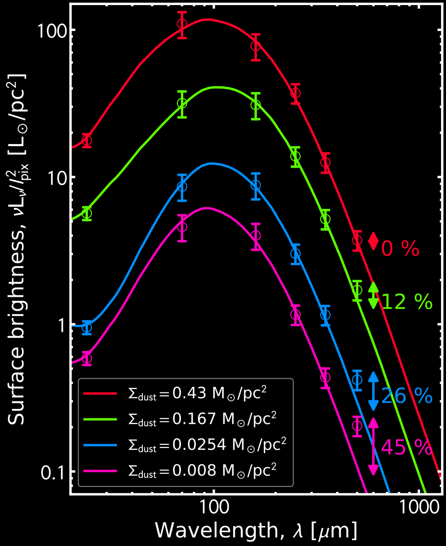


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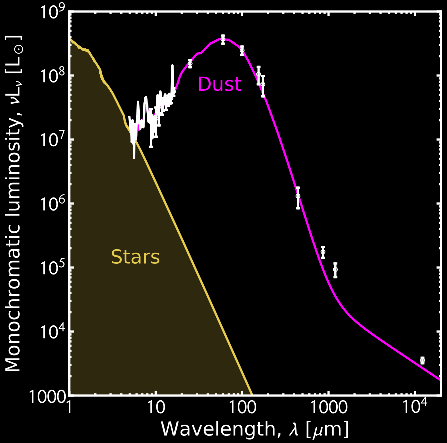

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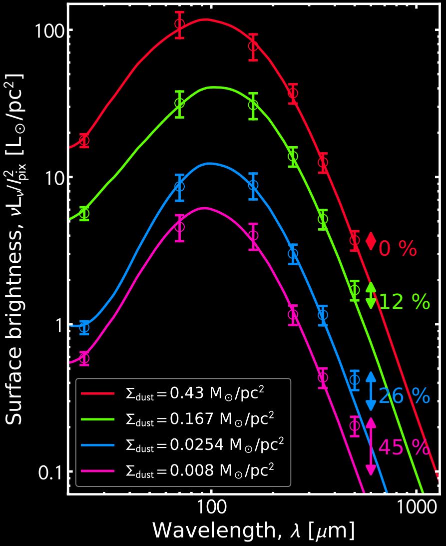


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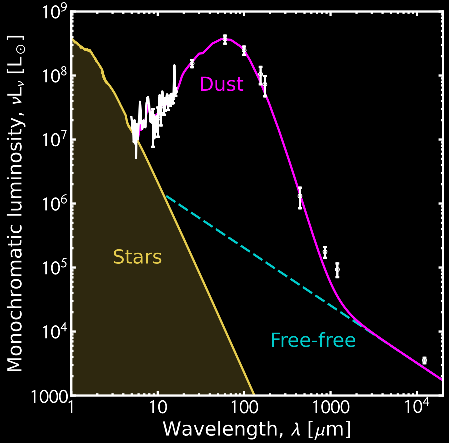

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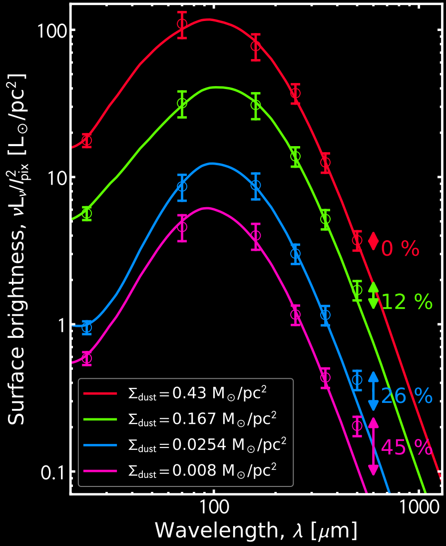


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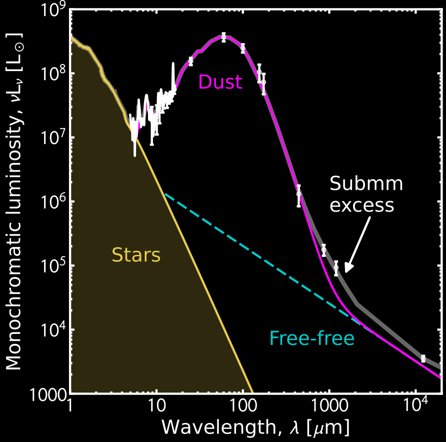

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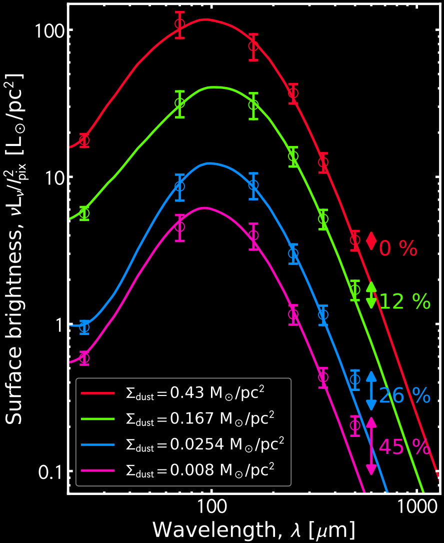


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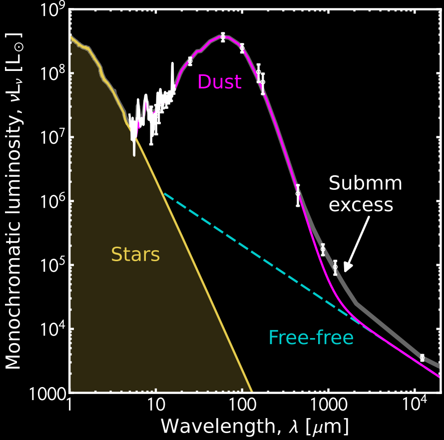


Observations corrected for $^{12}CO(J{=}2\rightarrow1)_{1.3mm}$ & $^{12}CO(J{=}3\rightarrow2)_{867\mu m}$.

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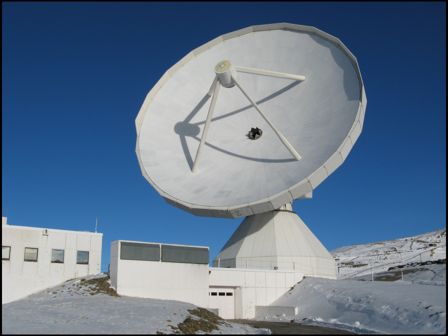
NIKA2 offers a unique opportunity to make sensitive millimeter maps of nearby galaxies ($\gtrsim 5'$), but:



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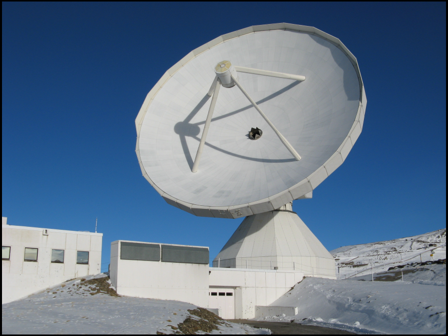

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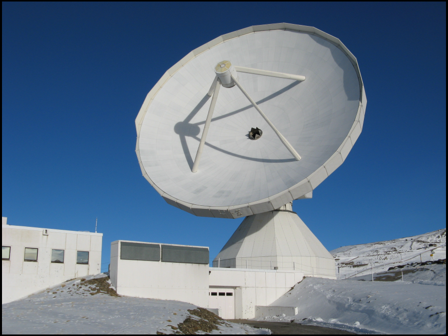

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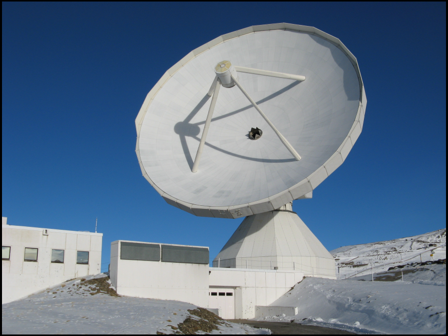

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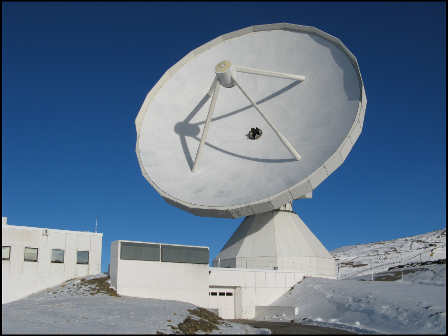

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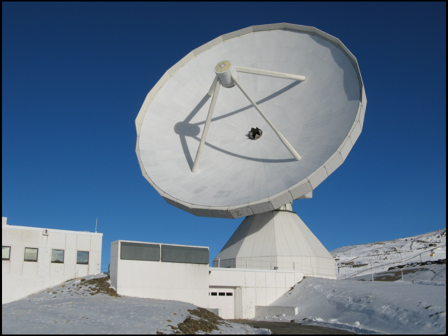

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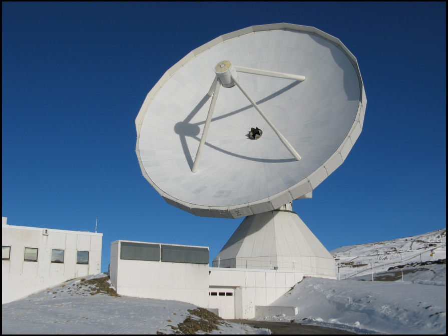

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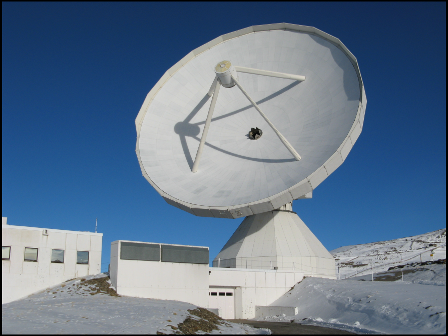

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- Contamination by Galactic cirruses (foreground) & CIB (background) $\Rightarrow$ confusion with the most diffuse emission of galaxies.
- Numerous physical processes from the studied galaxy and in competition:
  1. thermal dust emission;
  2. AME (non thermal dust emission);
  3. free-free;
  4. synchrotron;
  5. molecular lines.

# Talk T.O.C.


1. INTRODUCTION
   - The importance of the millimeter properties of dust grains
   - Studies of the submmillimeter excess
   - The challenging nature of these observations
2. THE SUBMILLIMETER EXCESS IN LOW-METALLICITY GALAXIES
   - The SEINFELD NIKA2 program
   - Multiwavelength, spatially-resolved SED modeling
   - Dependence of the submillimeter excess on the physical conditions
3. THE MILLIMETER PROPERTIES OF SOLAR-METALLICITY GALAXIES
   - The IMEGIN NIKA2 guaranteed time program
   - The long-wavelength grain opacity
   - Spectral decomposition of the mm-to-radio emission
4. CONCLUSION
   - Take-away points
   - Shameless ads
   - References

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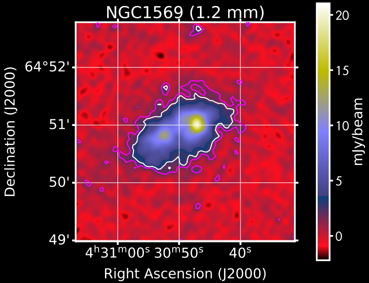


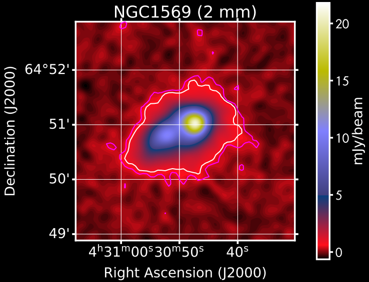

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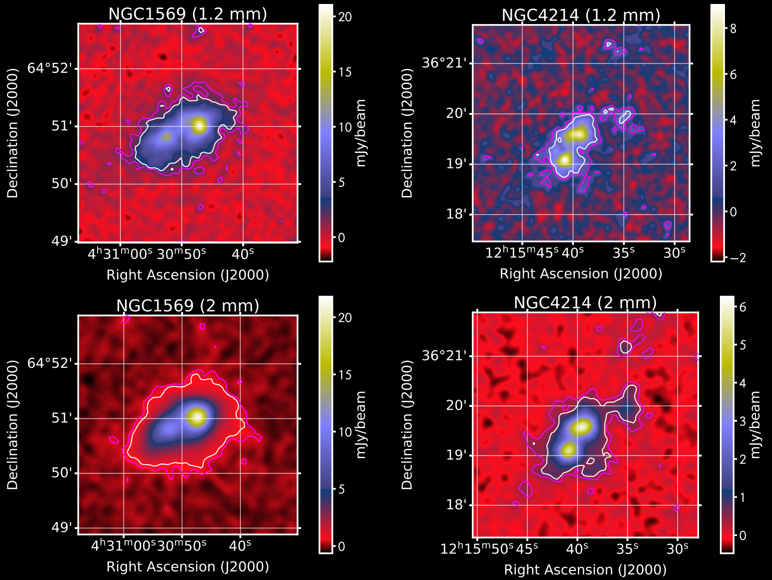

# SEINFELD | The SEINFELD NIKA2 Program

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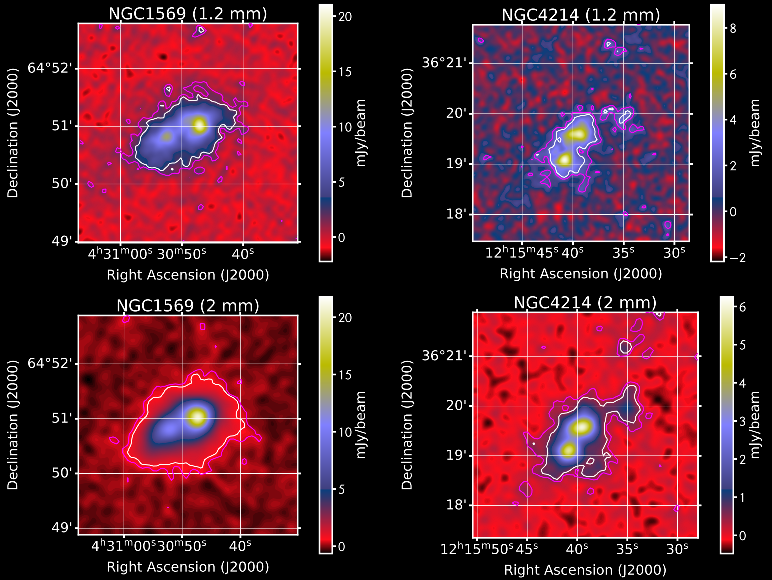


**NGC 4449**

⇒ will be observed in a few weeks.

# SEINFELD | Dependence on the Local Physical Conditions

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- Homogenized multi-$\lambda$ images fitted w/ THEMIS model (Jones et al., 2017) within the hierarchical Bayesian code, HerBIE (Galliano, 2018).

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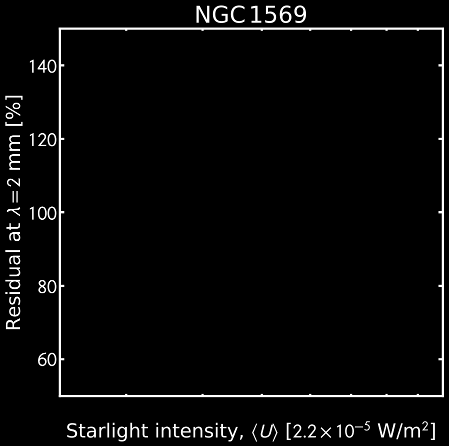

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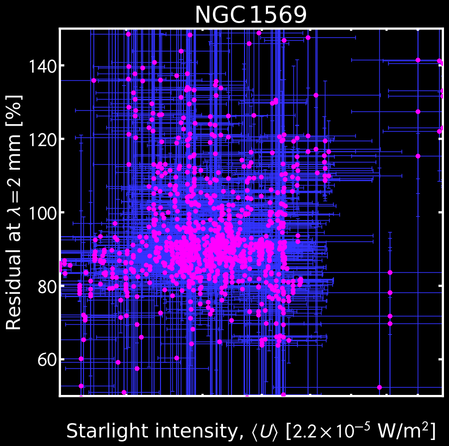

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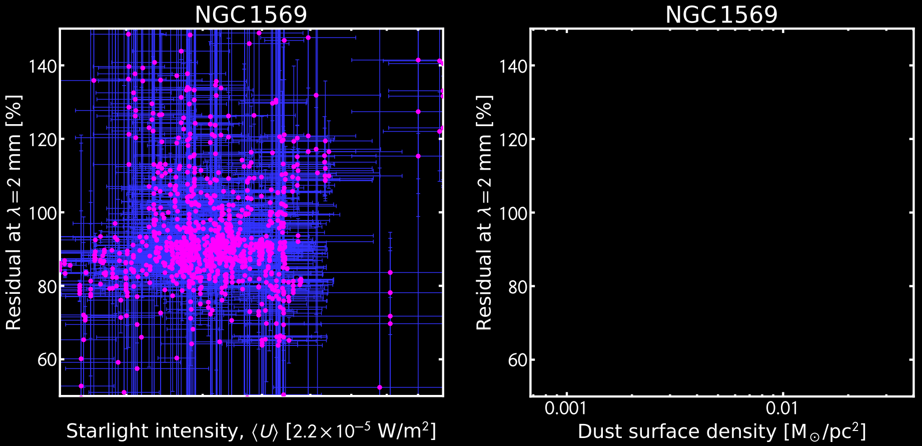

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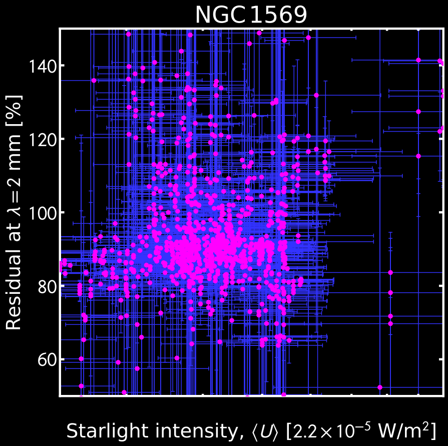


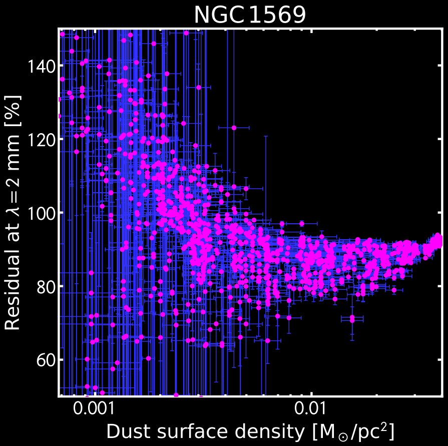

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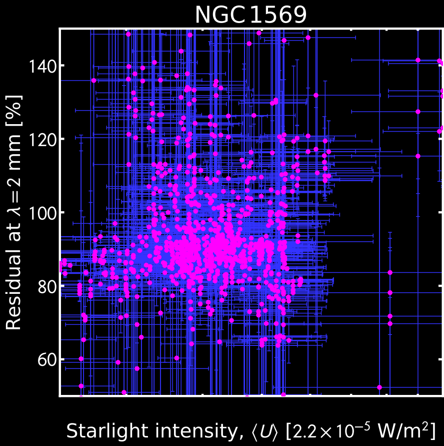
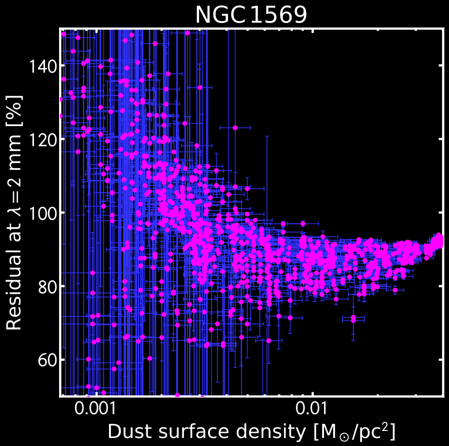
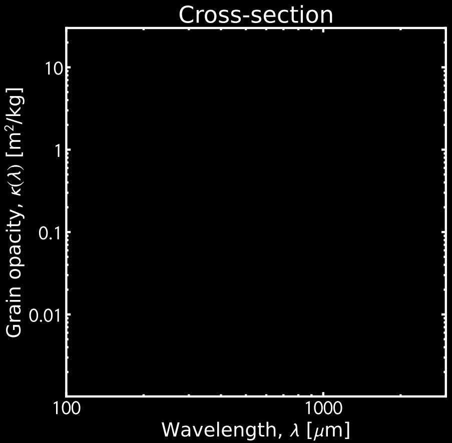
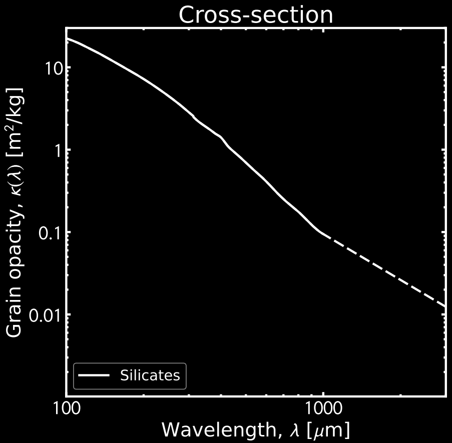
$\Rightarrow$ negative correlation with column density, but not with temperature ($\propto \langle U \rangle^{1/6}$).



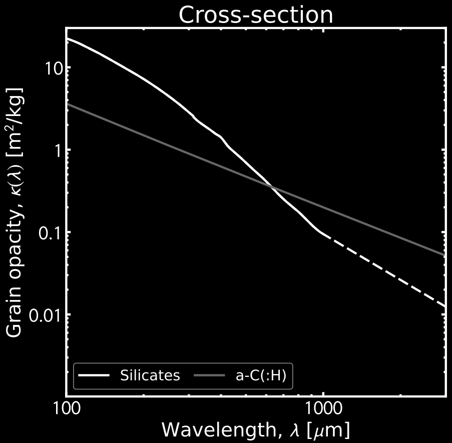



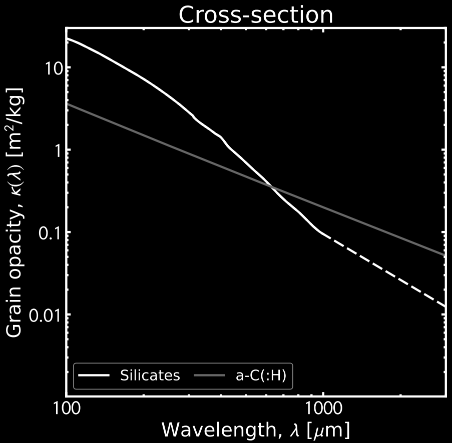
## SEINFELD | Working Hypothesis: The Dust Evolution Scenario




Cross-section
Grain opacity, $\kappa(\lambda)$ [$m^2$/kg]
10
1
0.1
0.01
Silicates
100
1000
Wavelength, $\lambda$ [$\mu$m]

# SEINFELD | Working Hypothesis: The Dust Evolution Scenario



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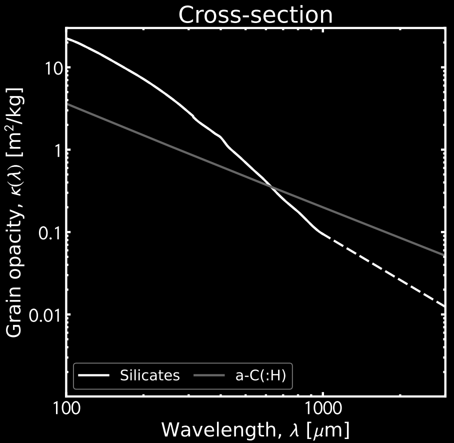


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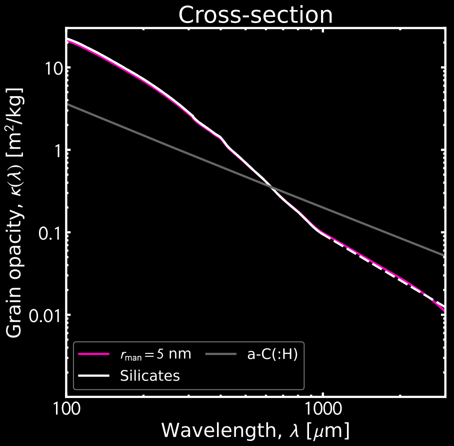


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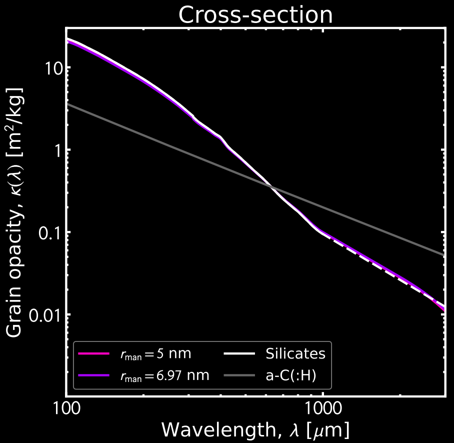


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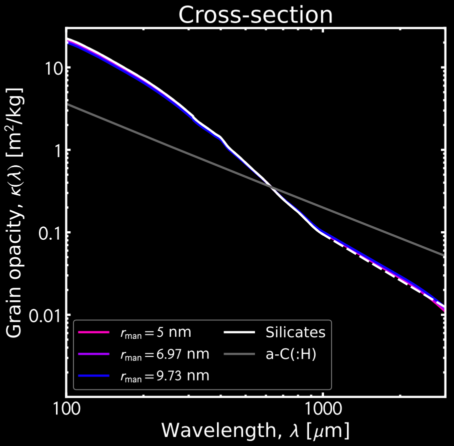


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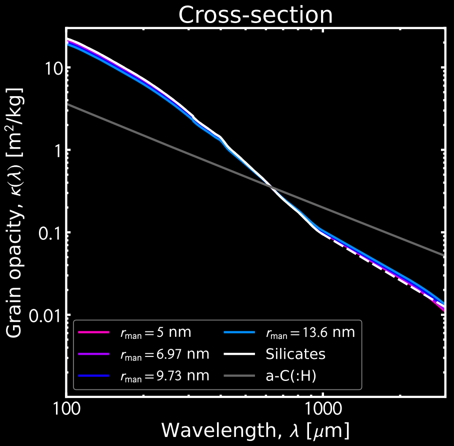


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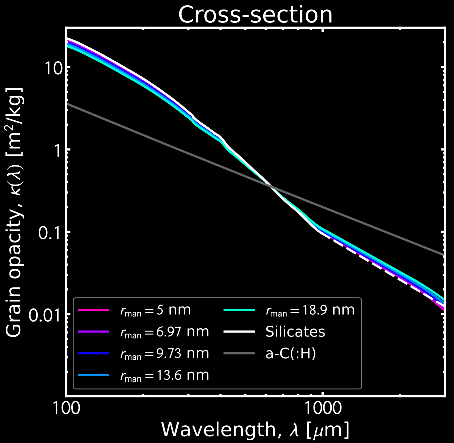


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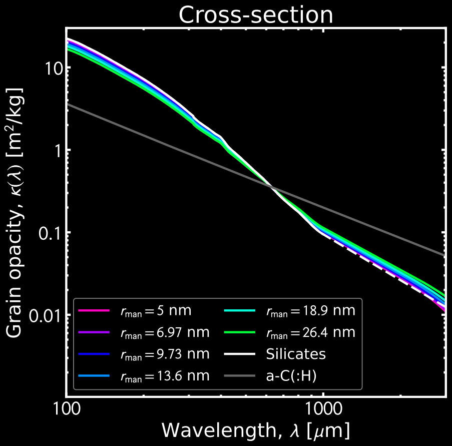


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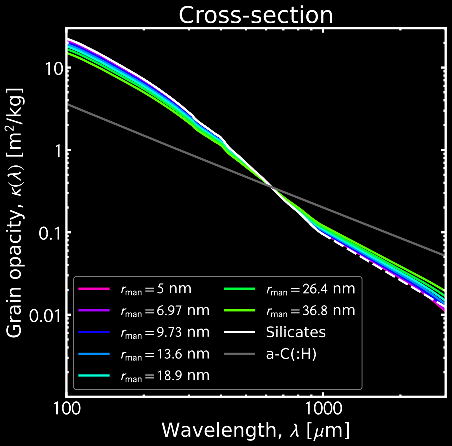


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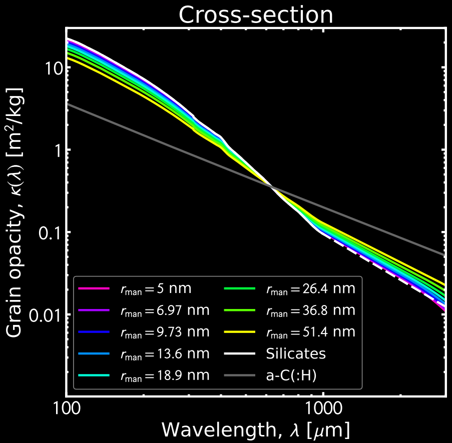


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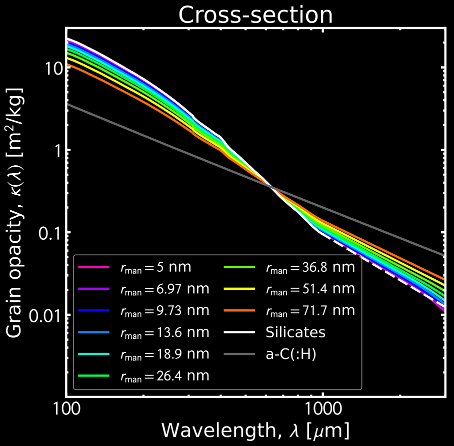


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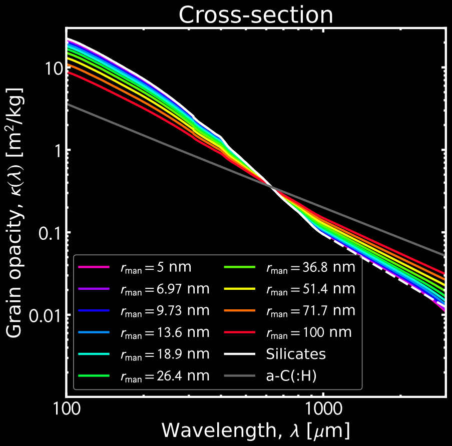


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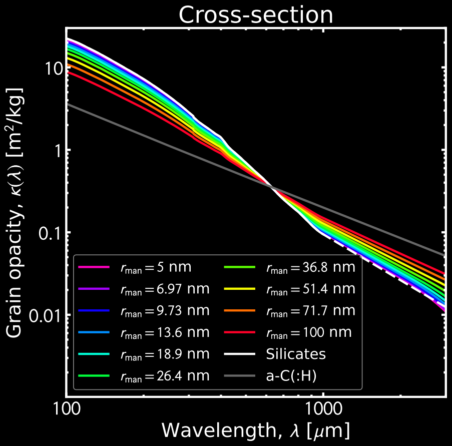


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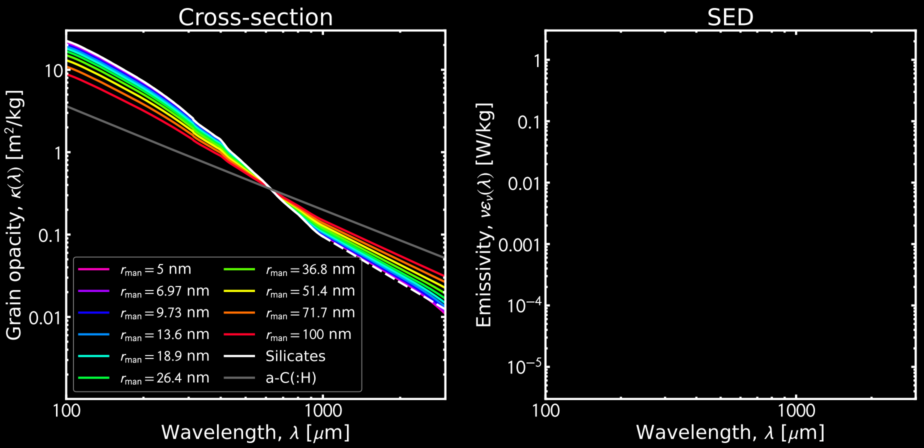


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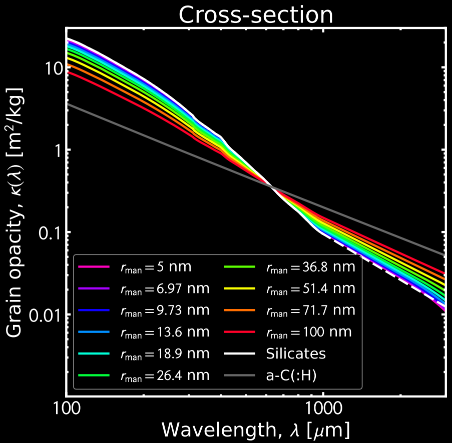


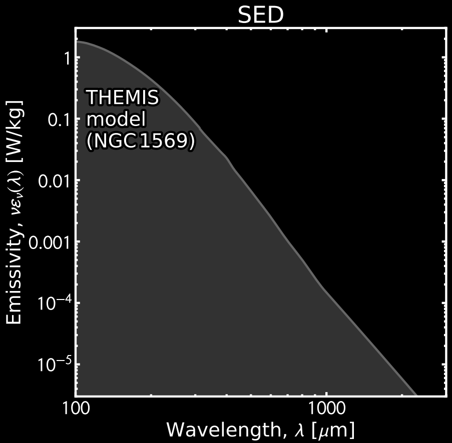


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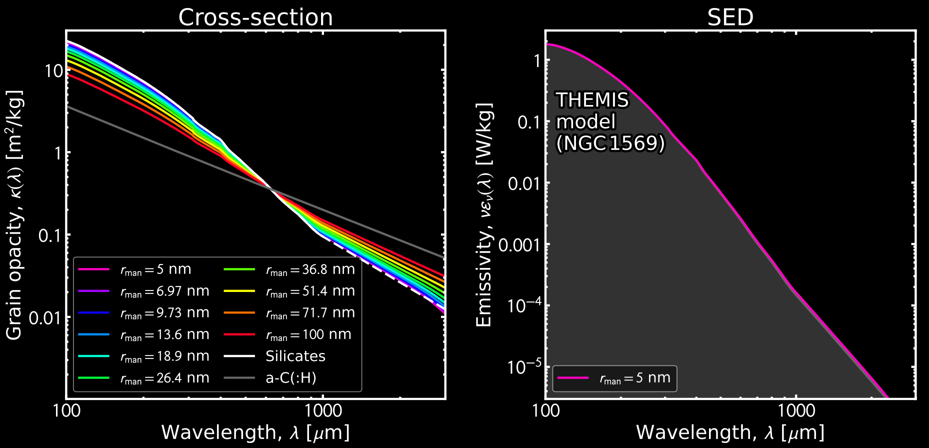


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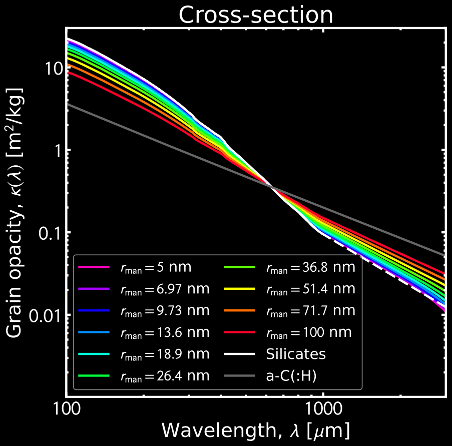


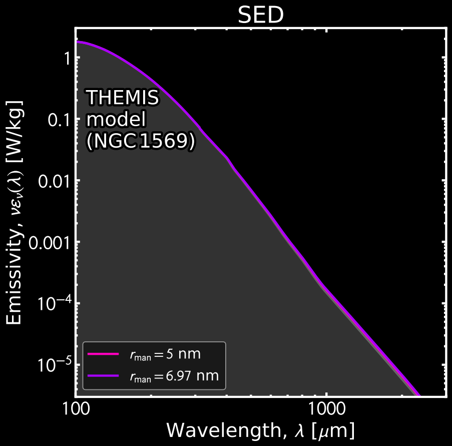


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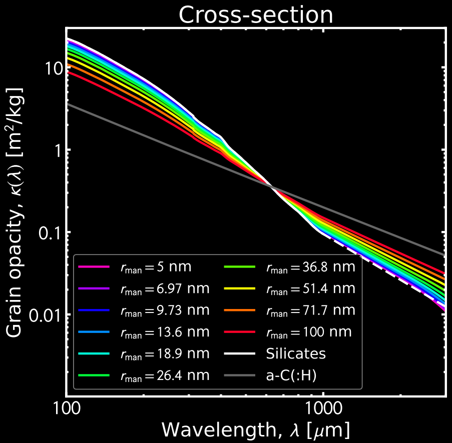


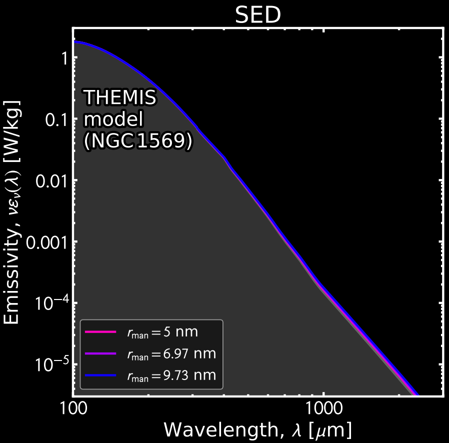


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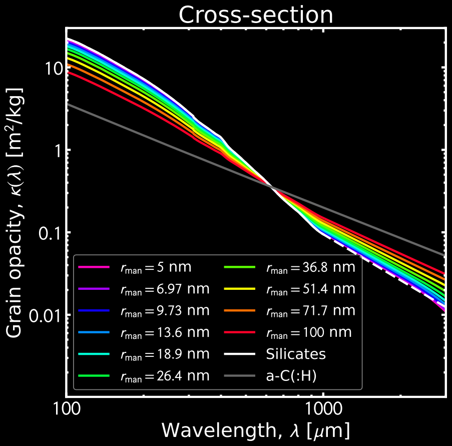


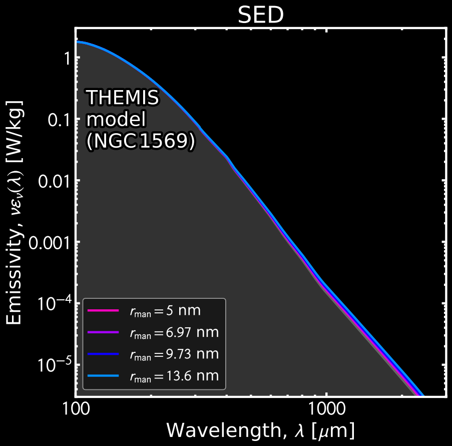


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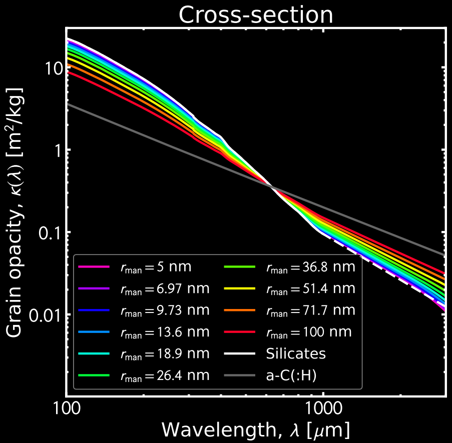


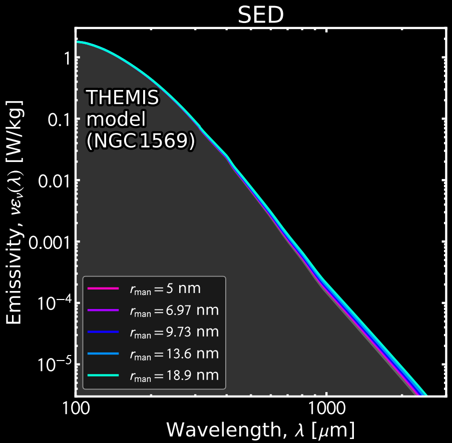


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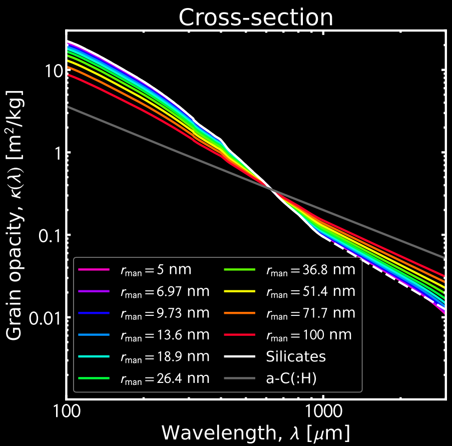


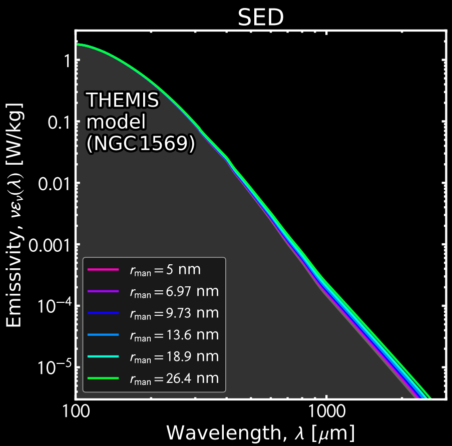


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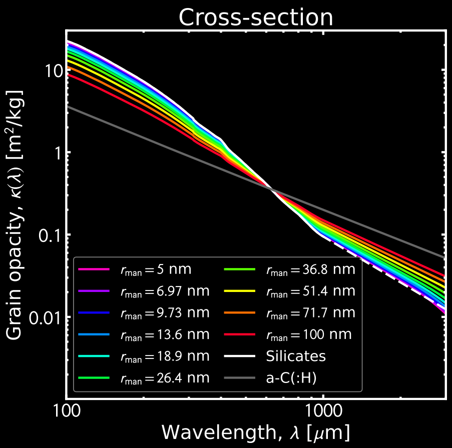


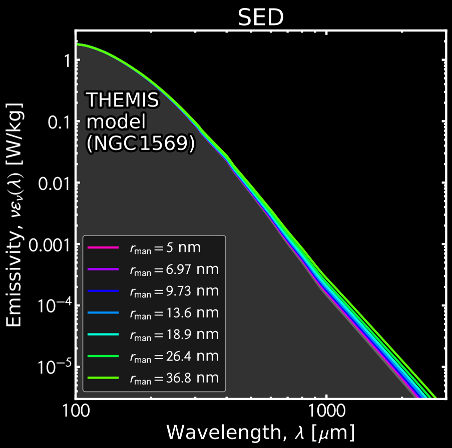


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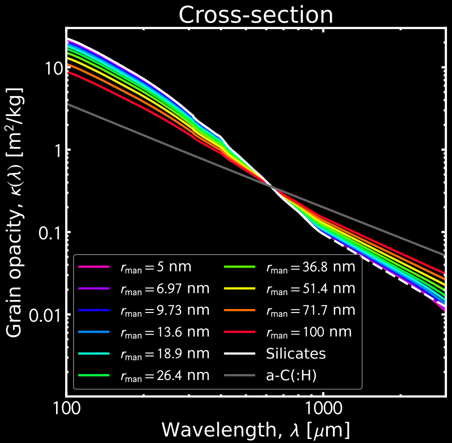


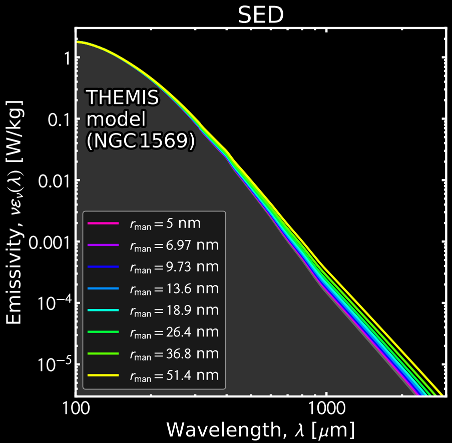


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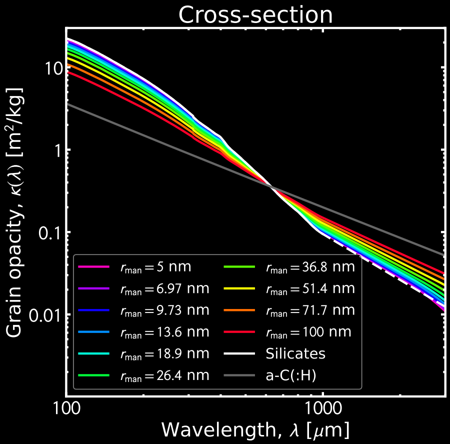


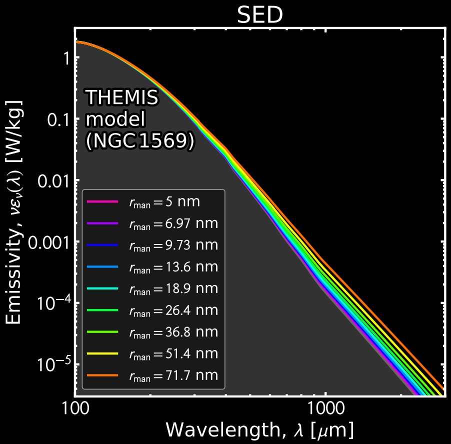


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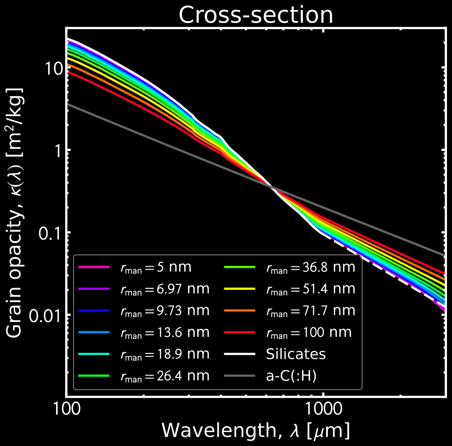


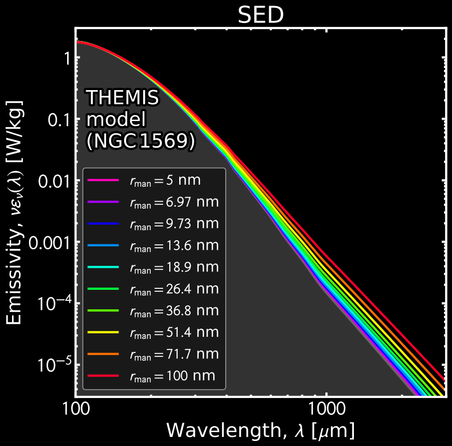


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   - The challenging nature of these observations
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   - The SEINFELD NIKA2 program
   - Multiwavelength, spatially-resolved SED modeling
   - Dependence of the submillimeter excess on the physical conditions
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   - The long-wavelength grain opacity
   - Spectral decomposition of the mm-to-radio emission
4. CONCLUSION
   - Take-away points
   - Shameless ads
   - References

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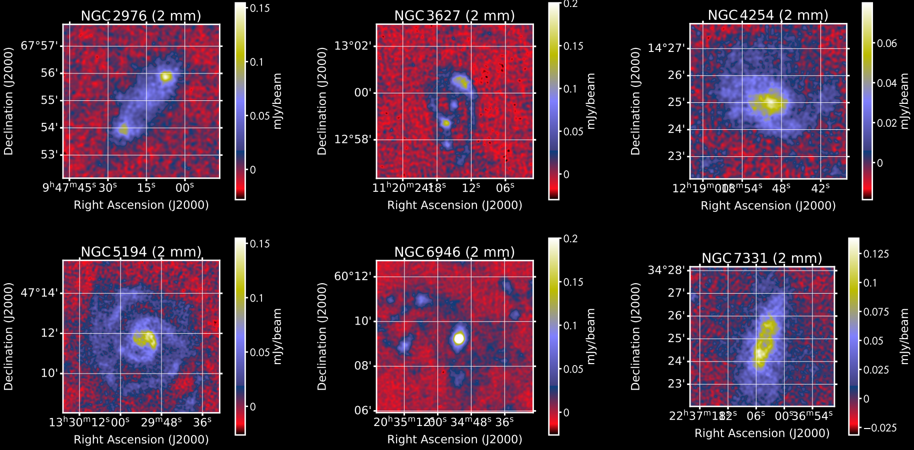


Preliminary data reduction of a 6 out of 22 IMEGIN galaxies.

# IMEGIN | The NIKA2 Guaranteed Time Program IMEGIN

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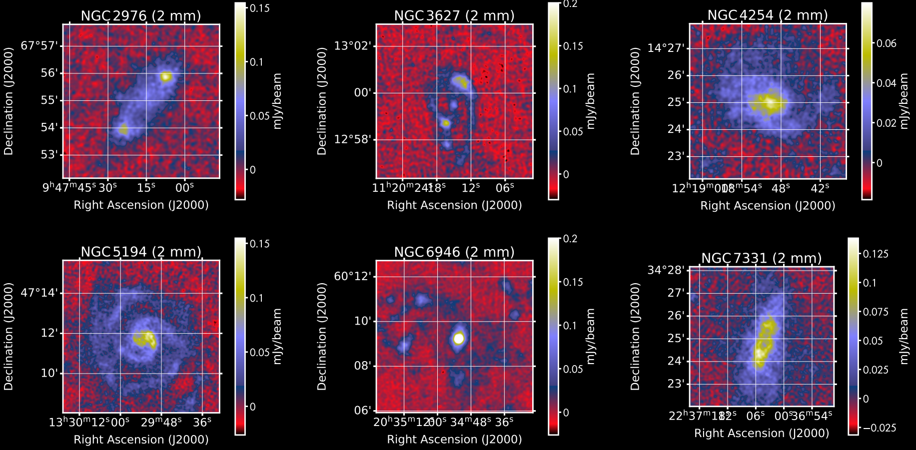


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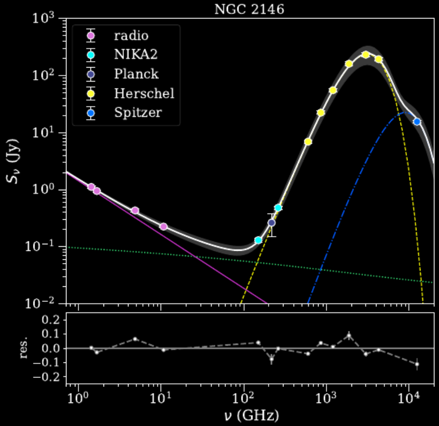
*Feathering* the data using *Planck* & ACT data (Smith et al., 2021).

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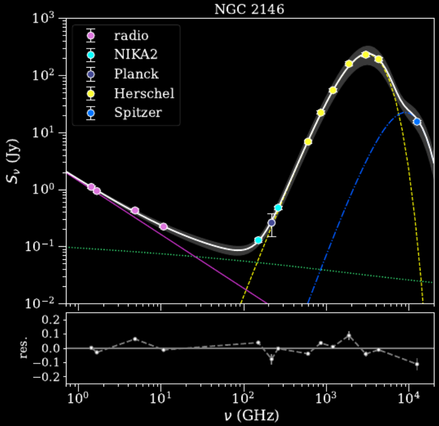


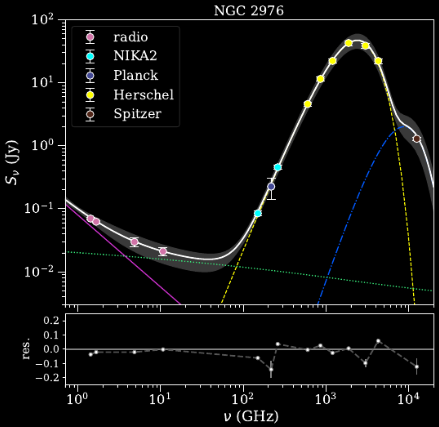


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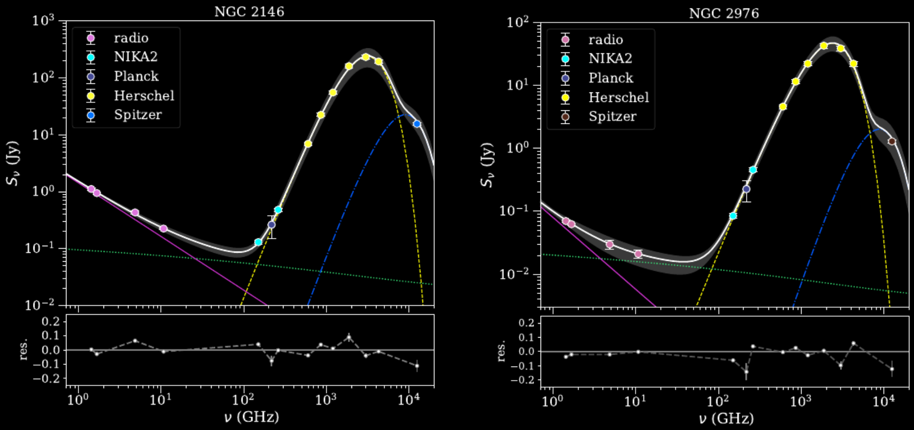
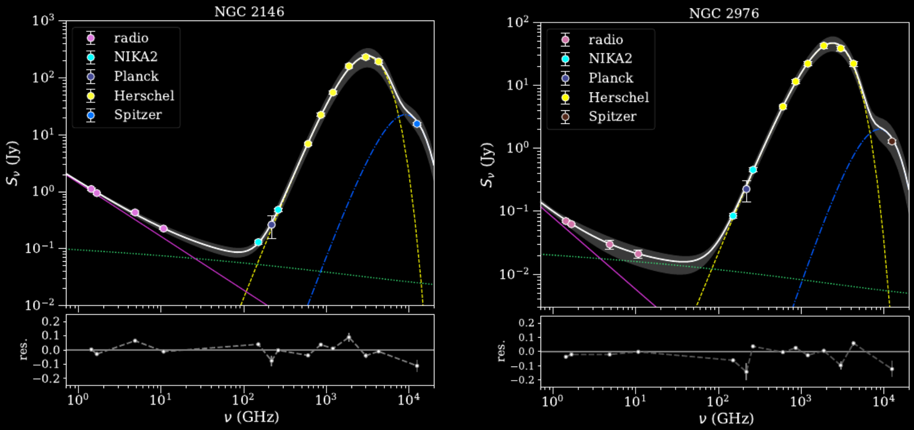



## SED decomposition

(Ejlali et al., 2024)




## SED decomposition

- 2 *Modified Black Bodies* (MBBs) + free-free + synchrotron w/ Bayesian inference.

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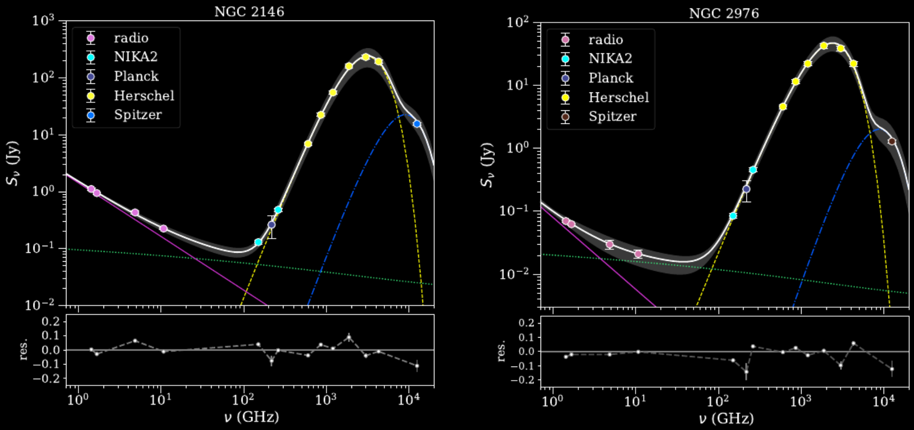


**SED decomposition**

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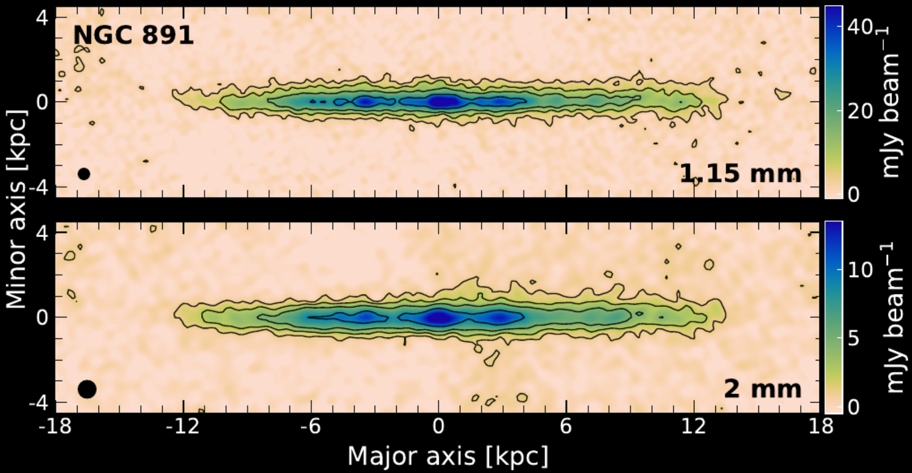
$\Rightarrow$ Estimate of the *emissivity index*, $\beta$ ($\kappa \propto \nu^\beta$): $\beta$(NGC 2146) $\simeq 1.72$ & $\beta$(NGC 2976) $\simeq 1.25$.

(Ejlali et al., 2024)

# IMEGIN | The Edge-On Galaxy NGC 891

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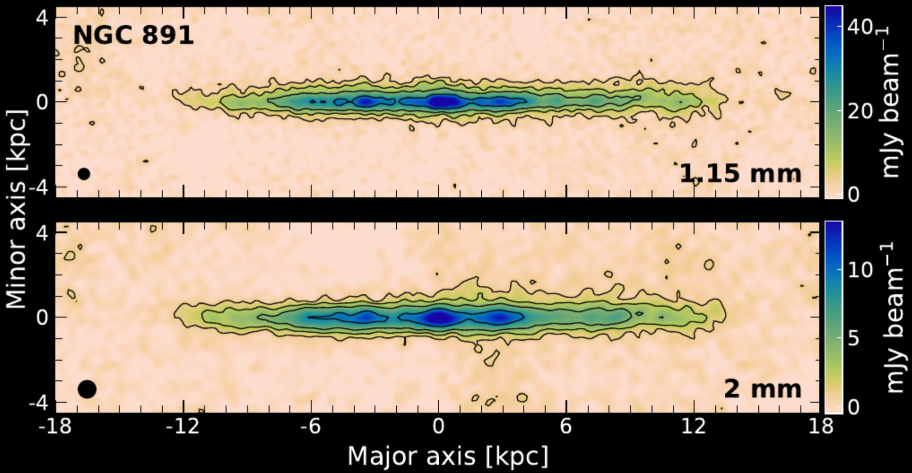


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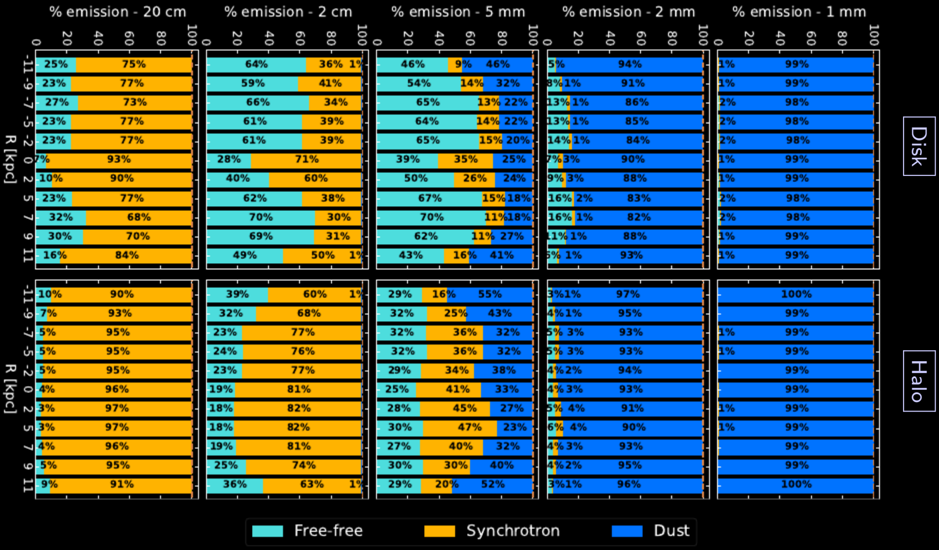
**Spatially-resolved SED modeling**

THEMIS model (Jones et al., 2017) within HerBIE (Galliano, 2018).

## IMEGIN | Radial Spectral Decomposition of NGC 891

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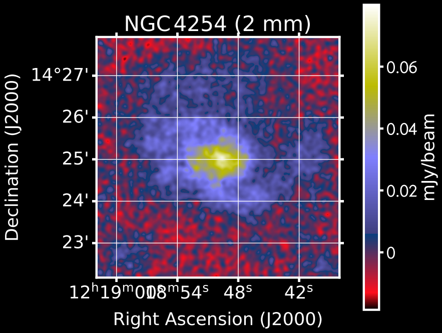


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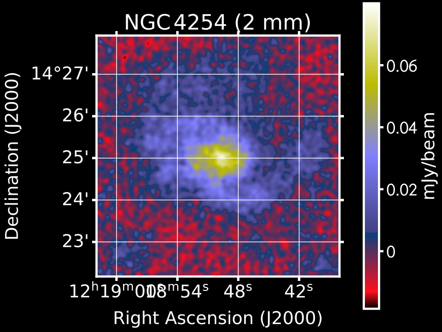


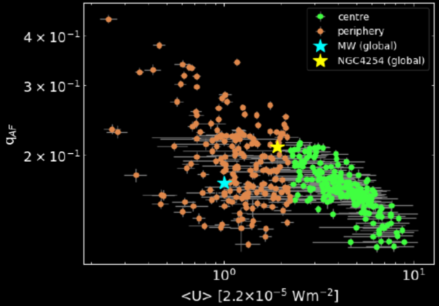


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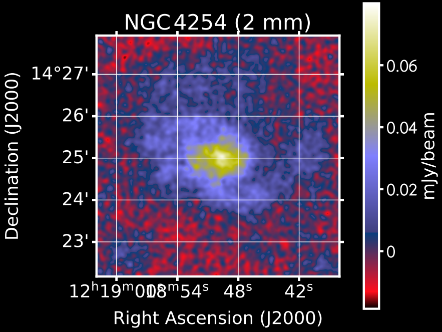


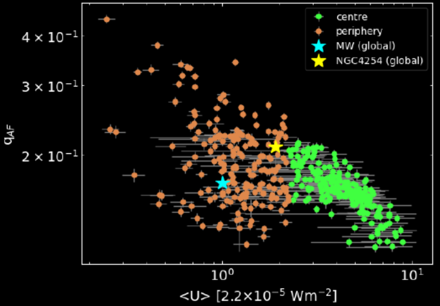


**Evidence of dust evolution in M 99**

Negative correlation b/w starlight intensity, $\langle U \rangle$, & fraction of small a-C(:H) grains, $q_{\rm AF}$ (carriers of the mid-IR Aromatic Features) $\Rightarrow$ photosublimation.

(Pantoni et al., 2024)

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   - Shameless ads
   - References

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- 22 gas-rich nearby galaxies have been observed, at $\lambda = 1.15$ & 2 mm, by the IMEGIN program $\rightarrow$ in the process feathering the maps to recover the filtered diffuse flux.
- These data are being used to systematically to study: (1) the far-IR-to-mm grain opacity; (2) the spectral decomposition of the radio continuum as a function of the environment; (3) dust evolution processes.

# Conclusion | Four Postdoc Positions on Dust in Galaxies, in France

**Project WIDENING: the NIKA2 data of nearby galaxies**

- Processing, interpreting and modeling the NIKA2 observations, together with ancillary data, of nearby galaxies (programs IMEGIN & SEINFELD).
- 3 year positions.

  **Postdoc at CEA Paris-Saclay:** https://aas.org/jobregister/ad/3972814b.
  **Postdoc at IRAM Grenoble:** https://aas.org/jobregister/ad/f7464d12.

**Project REDEEMING: a dust model for the Milky Way & the Magellanic clouds**

- Designing the first fully-constrained, extragalactic dust model, intrinsically parametrized by the metallicity, simultaneously fitting the emission, extinction and depletion of the diffuse ISM in the Milky Way and in the Large & Small Magellanic clouds.
- 3 year positions.

  **Postdoc at CEA Paris-Saclay:** https://aas.org/jobregister/ad/cbe51705.
  **Postdoc at IRAP Toulouse:** https://aas.org/jobregister/ad/105cc6d2.

**Next Galaxies' ISM Summer School: July 21 – August 1, 2025 – Banyuls-sur-mer France**

**Scope:** theory and observations of the ISM of nearby galaxies, with an emphasis on modern data analysis methods.

**Confirmed speakers:** Dalya BARON, Danielle BERG, Pierre CHAINAIS, Emmanuel DARTOIS, Simon GLOVER, Javier GOICOECHEA, Anna MCLEOD, Adeline PAIEMENT, Kate PATTLE, Donatella ROMANO, Antoine ROUEFF, Serena VITI.

**Registration:** January 27 – April 18, 2025.

**More info:** https://ismgalaxies2025.sciencesconf.org/?lang=en.

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