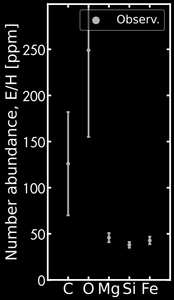
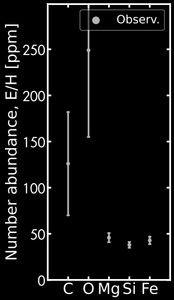
The PRIMA promise of deciphering interstellar dust evolution with observations of the nearby Universe

Frédéric GALLIANO

DAp-AIM, CEA Paris-Saclay, France

April 1st, 2025


Observ.
Number abundance, E/H [ppm]
0
50
100
150
200
250
C
O
Mg
Si
Fe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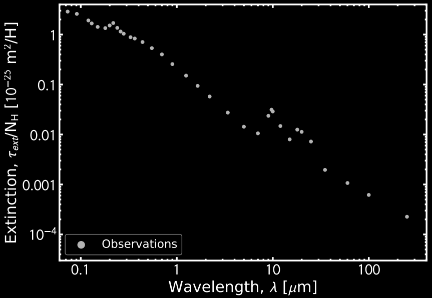
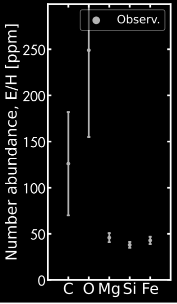

Observations
Extinction, τ_{ext}/N_H [10^{-25} m^2/H]
1
0.1
0.01
0.001
10^{-4}
0.1
1
10
100
Wavelength, λ [μm]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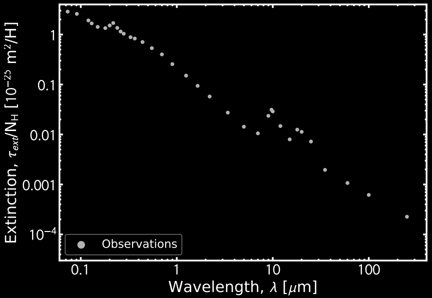
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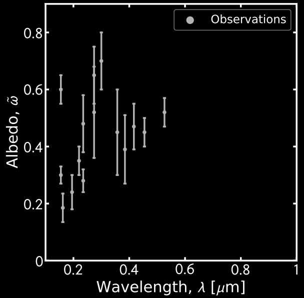
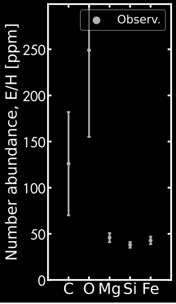

Observations
Albedo, $\tilde{\omega}$
0
0.2
0.4
0.6
0.8
0.2
0.4
0.6
0.8
1
Wavelength, λ [μm]


Number abundance, E/H [ppm]
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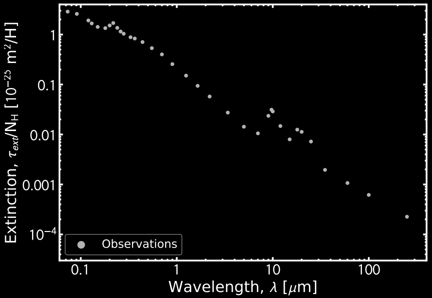
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0.01
0.1
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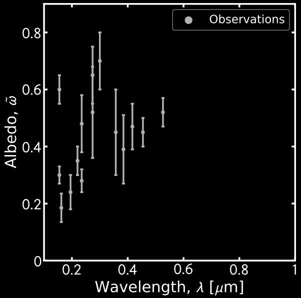
Wavelength, λ [μm]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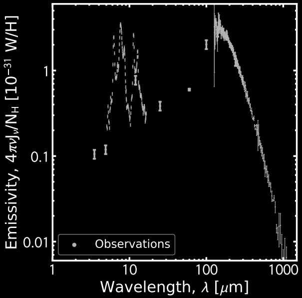
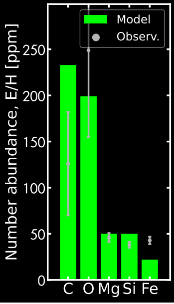
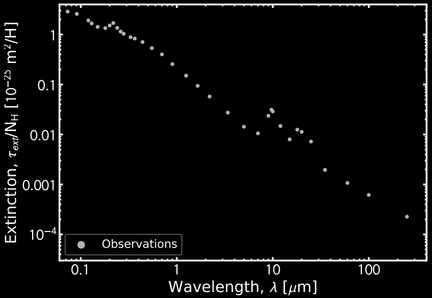
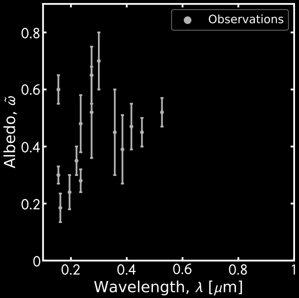
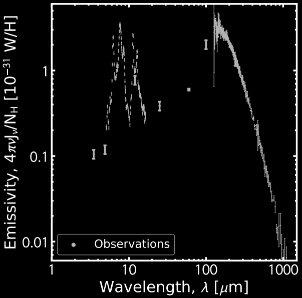
0.4
0.6
0.8
0.2
0.4
0.6
0.8
1
Wavelength, λ [μm]


Emissivity, $4\pi\nu j_\nu/N_H$ [10^{-31} W/H]
Observations
0.01
0.1
1
1
10
100
1000
Wavelength, λ [μm]

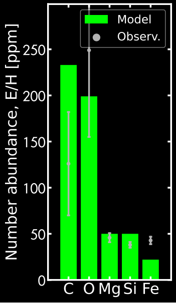


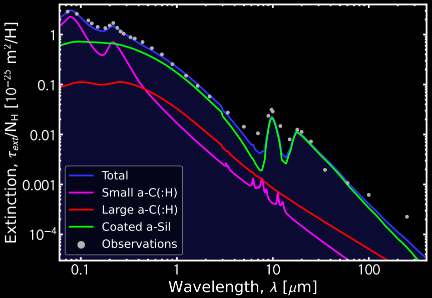


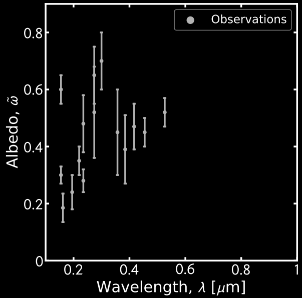


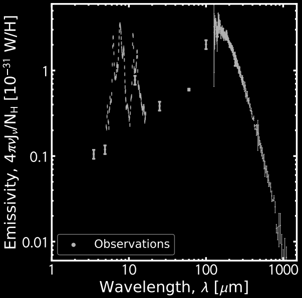


(THEMIS model; Jones et al. 2017; diffuse Galactic ISM)









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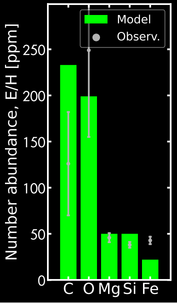

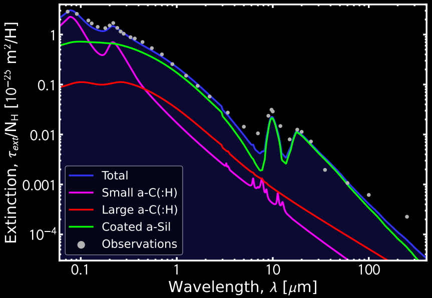

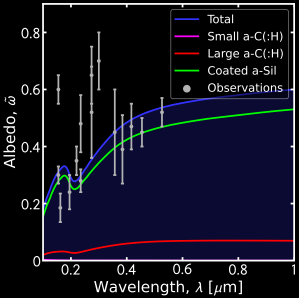

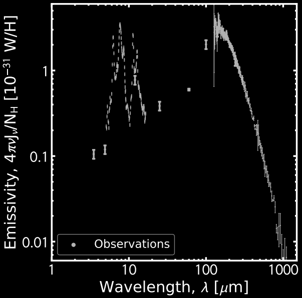

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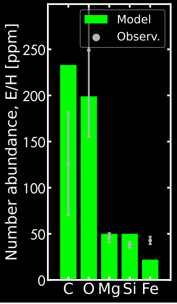
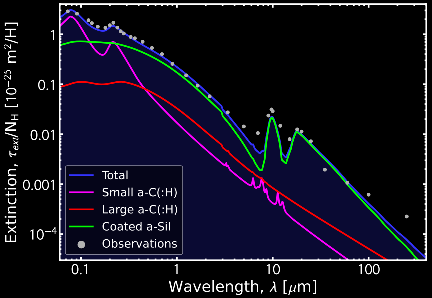
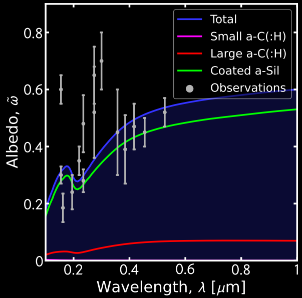
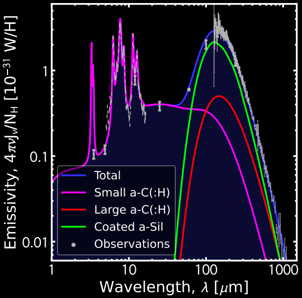
Motivations | State of the Art – The Diffuse Galactic ISM









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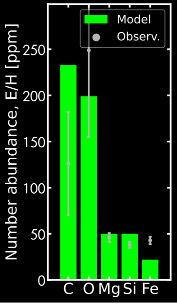

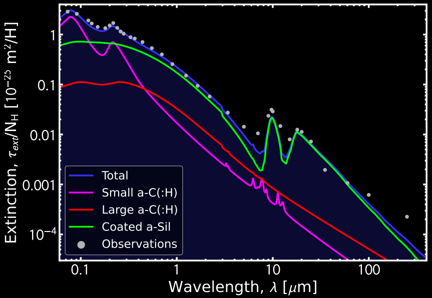

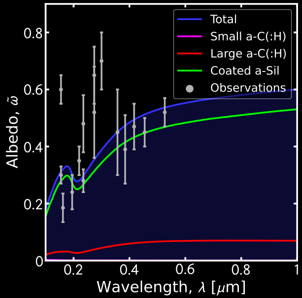

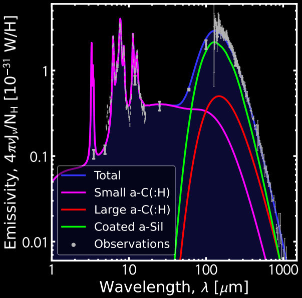

(THEMIS model; Jones et al. 2017; diffuse Galactic ISM)

+ polarization (Guillet et al., 2017; Hensley & Draine, 2023; Ysard et al., 2024)

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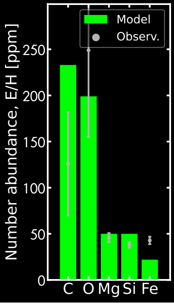

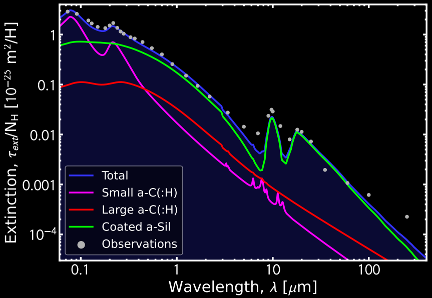

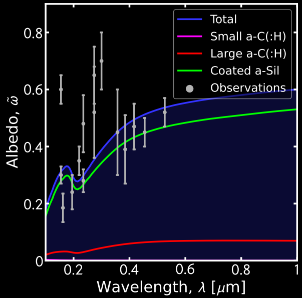

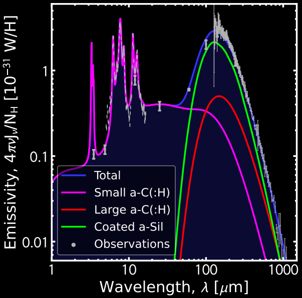

(THEMIS model; Jones et al. 2017; diffuse Galactic ISM)

+ polarization (Guillet et al., 2017; Hensley & Draine, 2023; Ysard et al., 2024)

$\nexists$ same set of constraints
$\in$ (external galaxies
$\vee$ dense regions)

Local dust evolution

Evolution of grain properties with G_0 & n:

Local dust evolution

Evolution of grain properties with G_0 & n:

- Mantle accretion

Local dust evolution

Evolution of grain properties with G_0 & n:

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Evolution of grain properties with G_0 & n:

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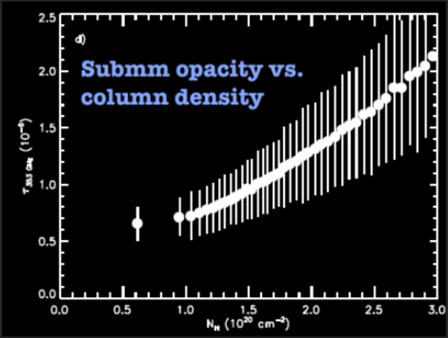

(Ysard et al., 2015)

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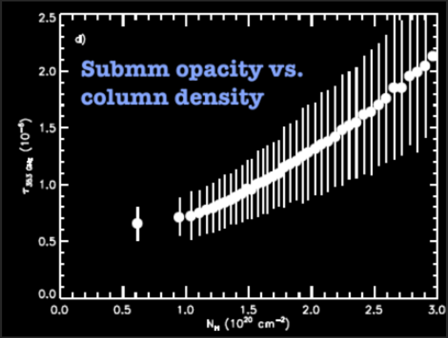

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Cosmic dust evolution

Evolution of grain content with Z

Local dust evolution

Evolution of grain properties with G_0 & n:

- Mantle accretion
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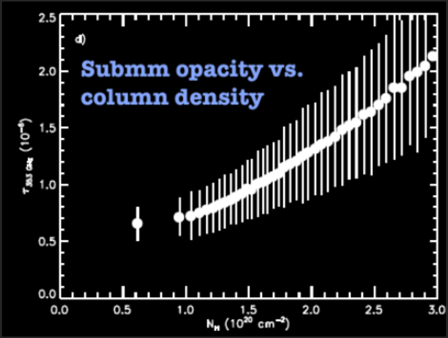
- Photoprocessing



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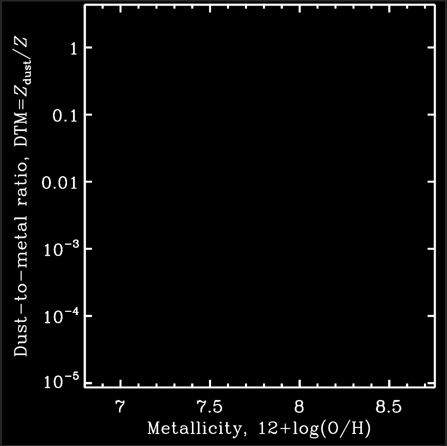
Cosmic dust evolution

Evolution of grain content with Z



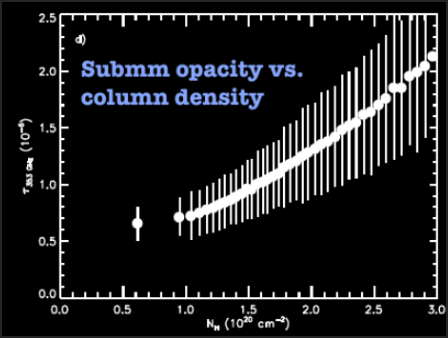
(Galliano et al., 2021)

Motivations | Local & Cosmic Dust Evolution

Local dust evolution

Evolution of grain properties with G_0 & n:

- Mantle accretion
- Change in size distribution
- Photoprocessing



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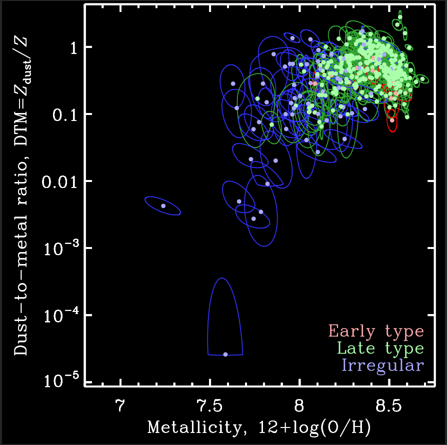

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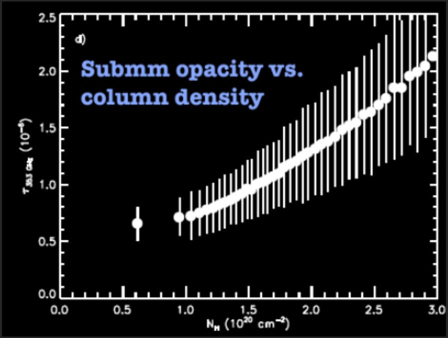
- Photoprocessing



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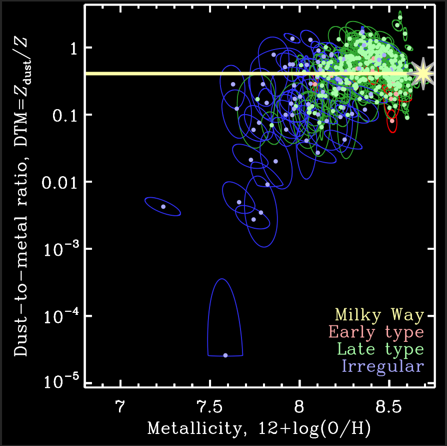

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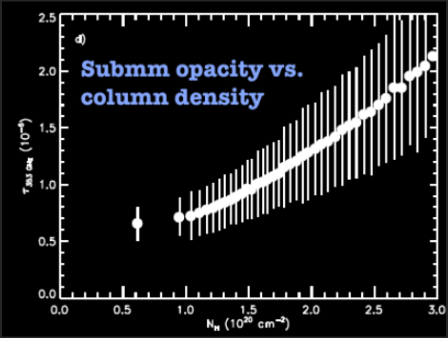

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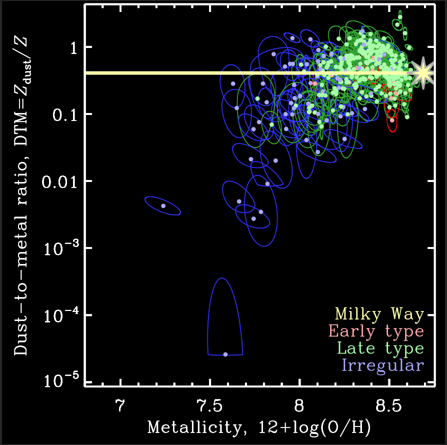

(Galliano et al., 2021)

⇒ we can not reliably model sub-pixel dust evolution in galaxies

The next steps to refine our understanding of interstellar dust properties & their evolution

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1. Being able to quantify local dust evolution when modeling galaxies

The next steps to refine our understanding of interstellar dust properties & their evolution

1. Being able to quantify local dust evolution when modeling galaxies
2. Understanding the unambiguous role of metallicity in cosmic dust evolution

The next steps to refine our understanding of interstellar dust properties & their evolution

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2. Understanding the unambiguous role of metallicity in cosmic dust evolution
3. Further constraints on interstellar grain mineralogy

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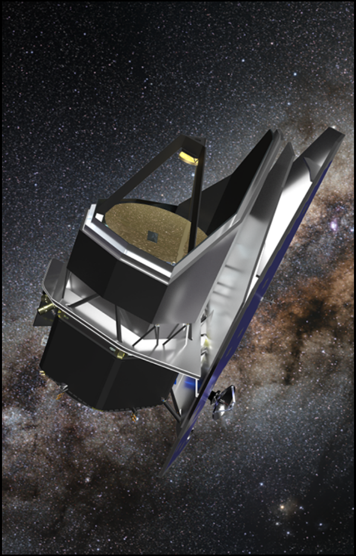
What PRIMA will bring



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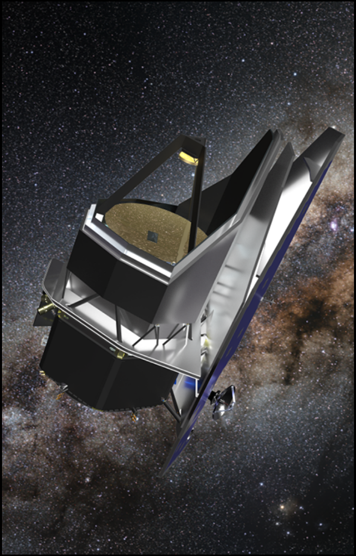
What PRIMA will bring

PRIMAger PPI: deep FIR maps over large areas + sensitive FIR polarization



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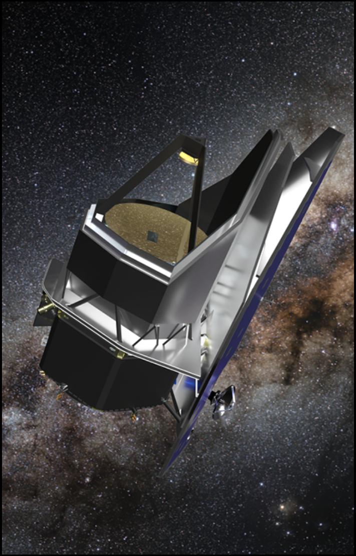
PRIMAger PHI: efficient spectral sampling of the MIR SED



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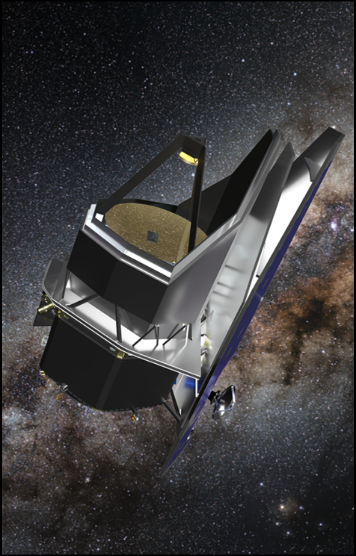
What PRIMA will bring

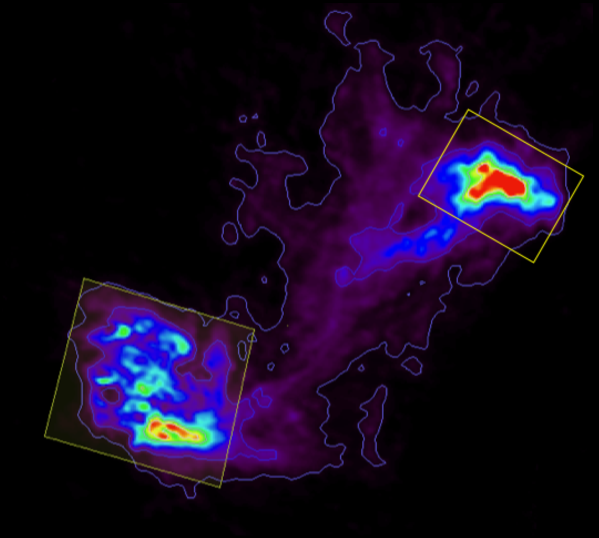
PRIMAger PPI: deep FIR maps over large areas + sensitive FIR polarization

PRIMAger PHI: efficient spectral sampling of the MIR SED

FIRESS: continuous medium-resolution spectroscopy over the MIR-to-FIR range



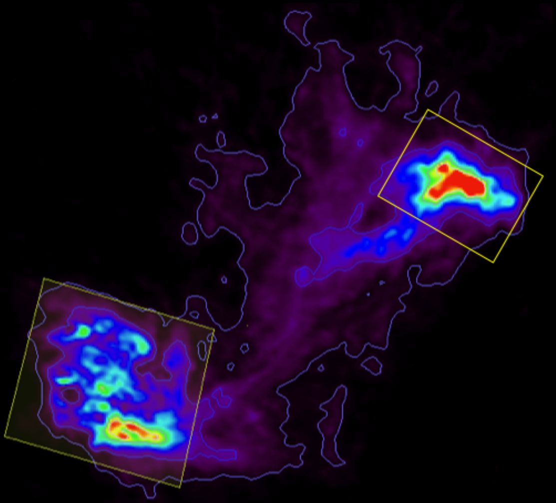
Science Case | Mapping the Diffuse Dust of the Magellanic Clouds



H I map of the Magellanic clouds (Brüns et al., 2005)
Contours: $N_{\rm H} = 10^{20} - 2 \times 10^{20}$ H/cm^2

Science Case | Mapping the Diffuse Dust of the Magellanic Clouds

A fully-constrained extragalactic dust model



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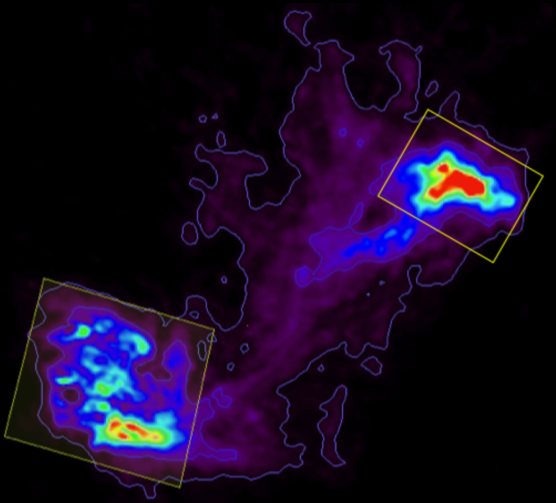
A fully-constrained extragalactic dust model

- ☒ UV-visible extinction curves



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A fully-constrained extragalactic dust model

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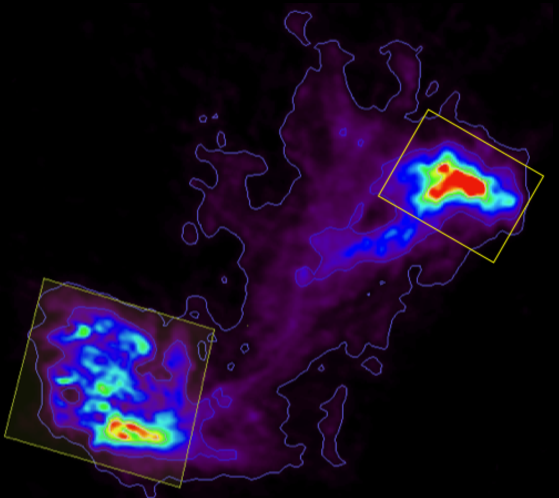
- ☒ Elemental depletions



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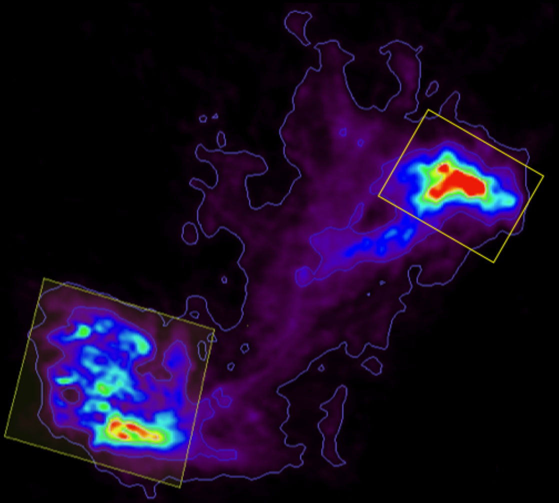
A fully-constrained extragalactic dust model

- ☒ UV-visible extinction curves
- ☒ Elemental depletions
- ☐ IR SED of the diffuse ISM



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A fully-constrained extragalactic dust model

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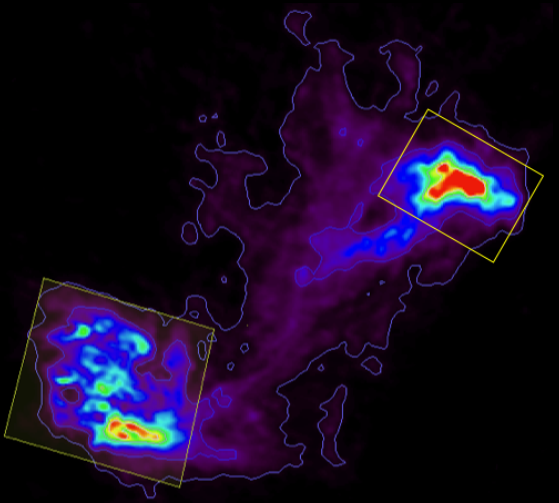
- ☒ Elemental depletions
- ☐ IR SED of the diffuse ISM $\Rightarrow$ sensitivity & confusion issue



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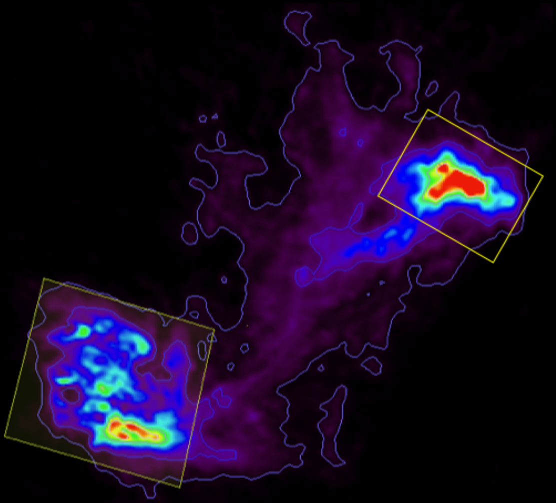
- ☒ Elemental depletions
- ☐ IR SED of the diffuse ISM $\Rightarrow$ sensitivity & confusion issue

$\Rightarrow$ need IR maps down to $N_\mathrm{H} \simeq 2 \times 10^{20}\ \mathrm{H/cm^2}$ at $\simeq 28''$ + redundancy



H I map of the Magellanic clouds (Brüns et al., 2005)
Contours: $N_\mathrm{H} = 10^{20} - 2 \times 10^{20}\ \mathrm{H/cm^2}$

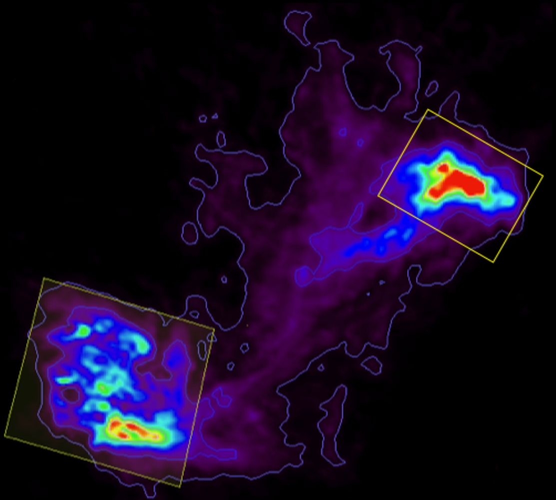
Science Case | Mapping the Diffuse Dust of the Magellanic Clouds

A fully-constrained extragalactic dust model

- ☒ UV-visible extinction curves
- ☒ Elemental depletions
- ☐ IR SED of the diffuse ISM $\Rightarrow$ sensitivity & confusion issue

$\Rightarrow$ need IR maps down to $N_\mathrm{H} \simeq 2 \times 10^{20}\ \mathrm{H/cm^2}$ at $\simeq 28''$ + redundancy

Possible PRIMAger strategy



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A fully-constrained extragalactic dust model

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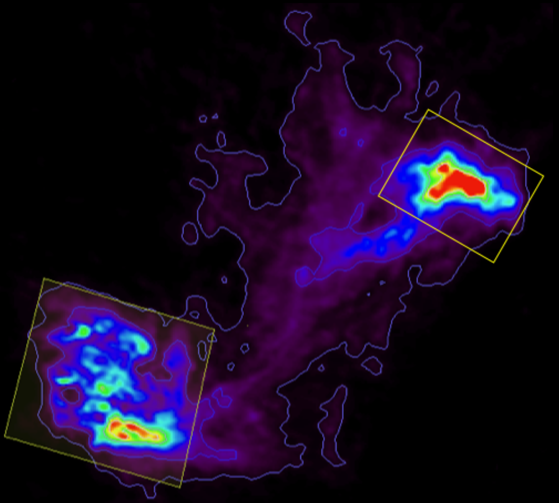
- $\Rightarrow$ need IR maps down to $N_\mathrm{H} \simeq 2 \times 10^{20}\ \mathrm{H/cm^2}$ at $\simeq$ 28" + redundancy

Possible PRIMAger strategy

Total power (FIR): full PPI1–PPI4 maps (313 h)



H I map of the Magellanic clouds (Brüns et al., 2005)
Contours: $N_\mathrm{H} = 10^{20} - 2 \times 10^{20}\ \mathrm{H/cm^2}$

A fully-constrained extragalactic dust model

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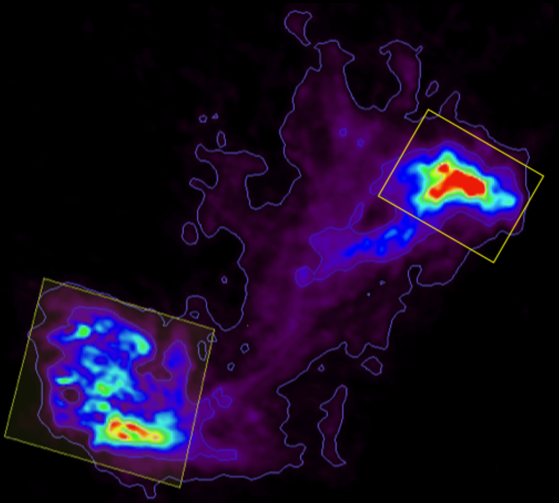
Possible PRIMAger strategy

Total power (FIR): full PPI1–PPI4 maps (313 h)

Total power (MIR): $0.2^\circ \times 0.2^\circ$ maps w/ PHI1–PHI2 (380 h)



H I map of the Magellanic clouds (Brüns et al., 2005)
Contours: $N_{\rm H} = 10^{20} - 2 \times 10^{20}\ \mathrm{H/cm^2}$

A fully-constrained extragalactic dust model

- ☒ UV-visible extinction curves
- ☒ Elemental depletions
- ☐ IR SED of the diffuse ISM $\Rightarrow$ sensitivity & confusion issue

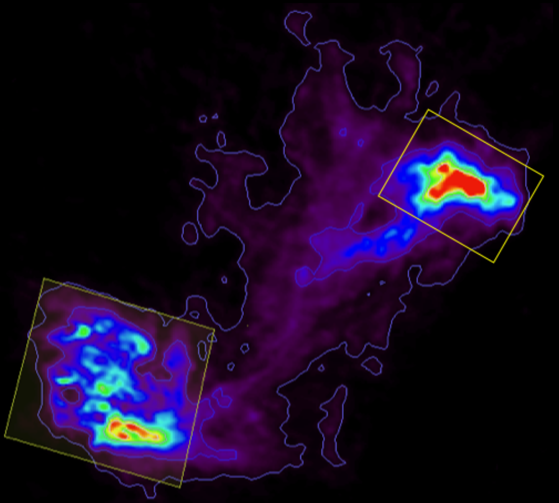
$\Rightarrow$ need IR maps down to $N_\mathrm{H} \simeq 2 \times 10^{20}\ \mathrm{H/cm^2}$ at $\simeq$ 28" + redundancy

Possible PRIMAger strategy

Total power (FIR): full PPI1–PPI4 maps (313 h)

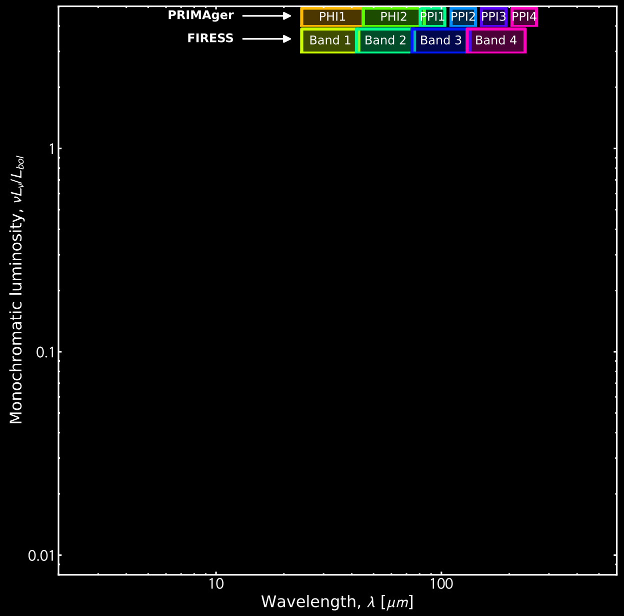
Total power (MIR): $0.2^\circ \times 0.2^\circ$ maps w/ PHI1–PHI2 (380 h)

Polarization: $0.2^\circ \times 0.2^\circ$ maps w/ PPI2–PPI4 (220 h)

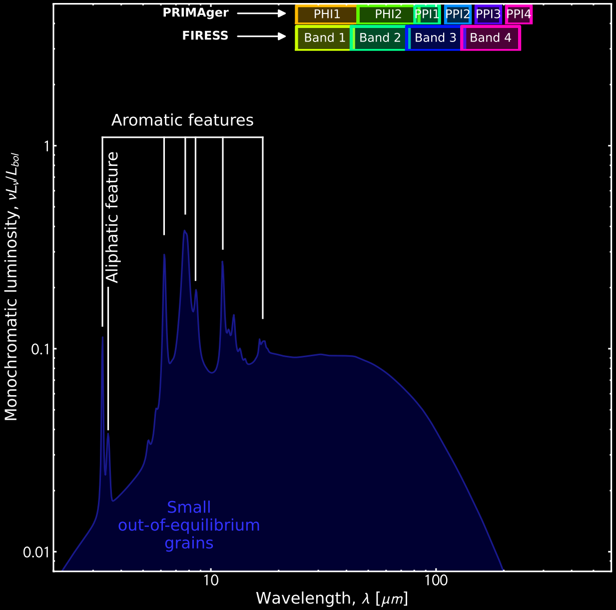


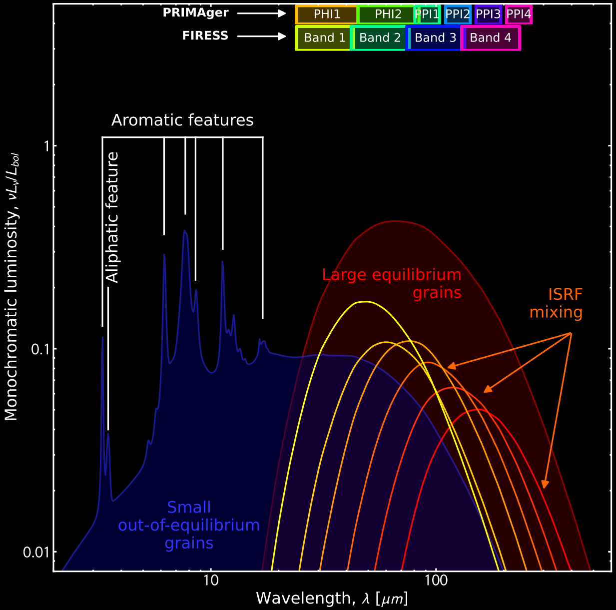
H I map of the Magellanic clouds (Brüns et al., 2005)
Contours: $N_\mathrm{H} = 10^{20} - 2 \times 10^{20}\ \mathrm{H/cm^2}$

Science Case | Surveying the Mineralogical Diversity of the ISM

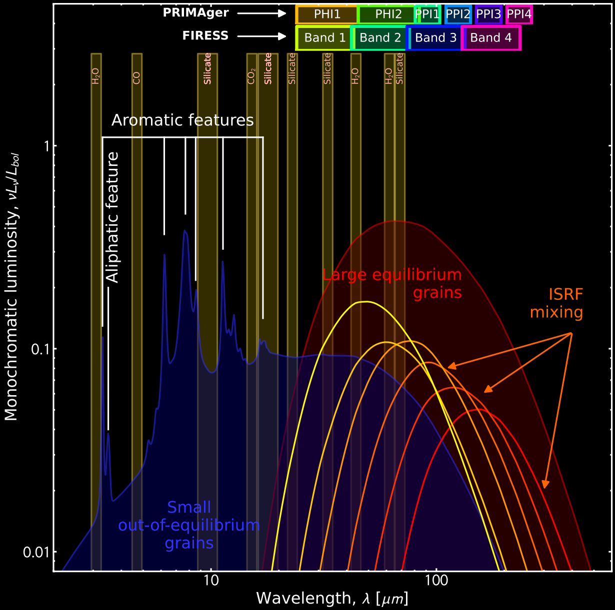


Science Case | Surveying the Mineralogical Diversity of the ISM

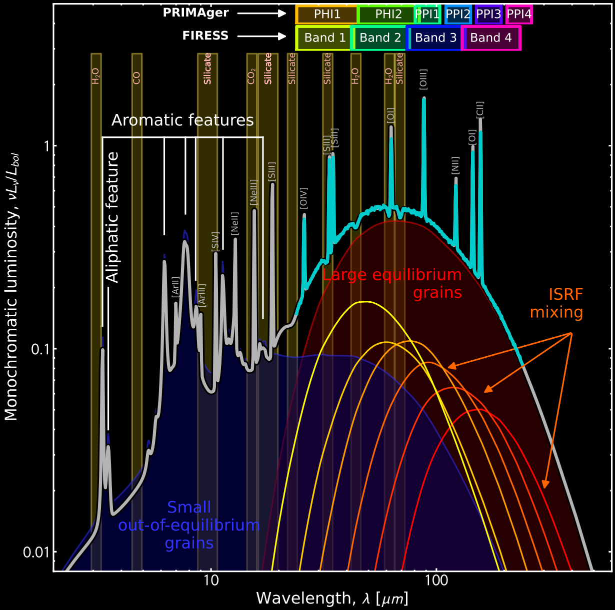



PRIMAger
FIRESS
PHI1
PHI2
PPI1
PPI2
PPI3
PPI4
Band 1
Band 2
Band 3
Band 4
Aromatic features
Aliphatic feature
Large equilibrium grains
ISRF mixing
Small out-of-equilibrium grains
Monochromatic luminosity, $\nu L_\nu / L_{bol}$
Wavelength, λ [μm]
1
0.1
0.01
10
100

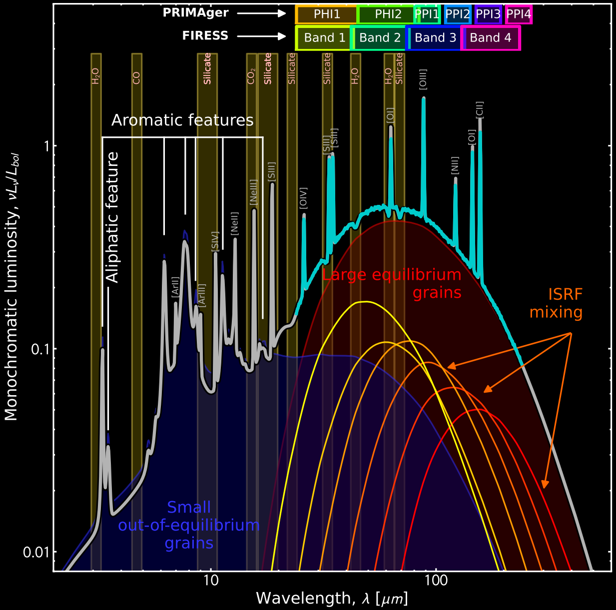
Science Case | Surveying the Mineralogical Diversity of the ISM



Science Case | Surveying the Mineralogical Diversity of the ISM

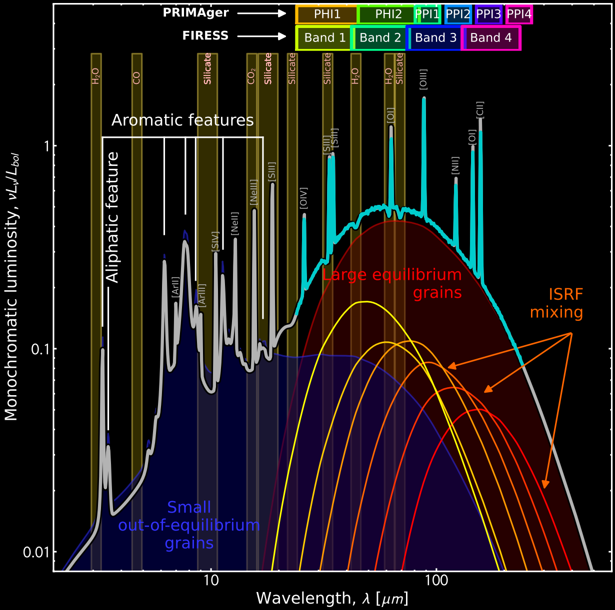


Science Case | Surveying the Mineralogical Diversity of the ISM



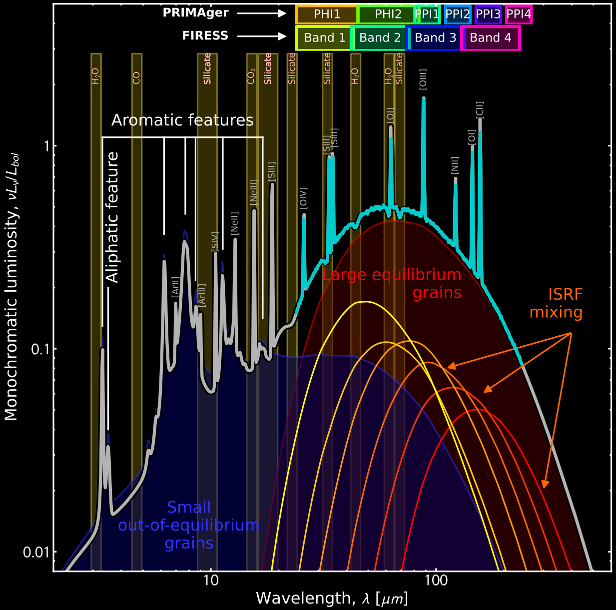
Deep MIR-to-FIR medium-resolution spectroscopy

Science Case | Surveying the Mineralogical Diversity of the ISM



Deep MIR-to-FIR medium-resolution spectroscopy

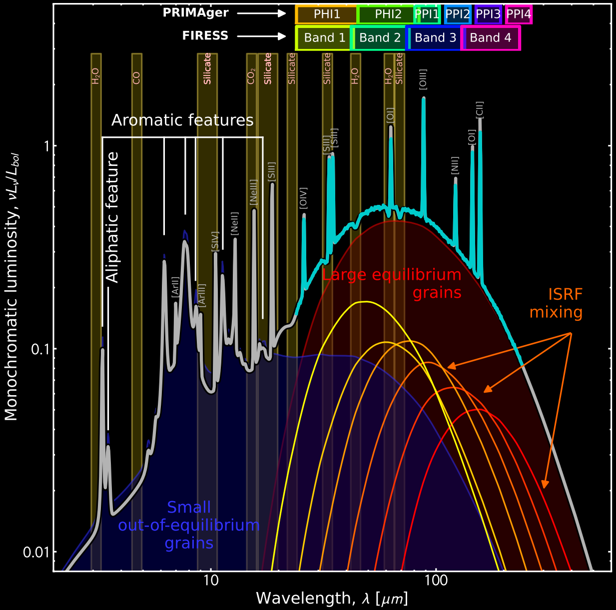
⇒ No full-range IR spectrometer since ISOSWS/ISOLWS



Deep MIR-to-FIR medium-resolution spectroscopy

⇒ No full-range IR spectrometer since ISOSWS/ISOLWS

- Constrain silicate crystallinity

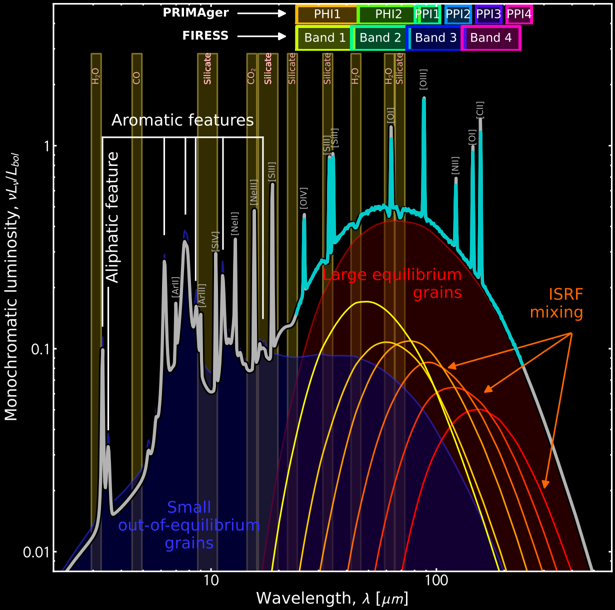


Deep MIR-to-FIR medium-resolution spectroscopy

⇒ No full-range IR spectrometer since ISOSWS/ISOLWS

- Constrain silicate crystallinity
- Look for various oxides

Science Case | Surveying the Mineralogical Diversity of the ISM

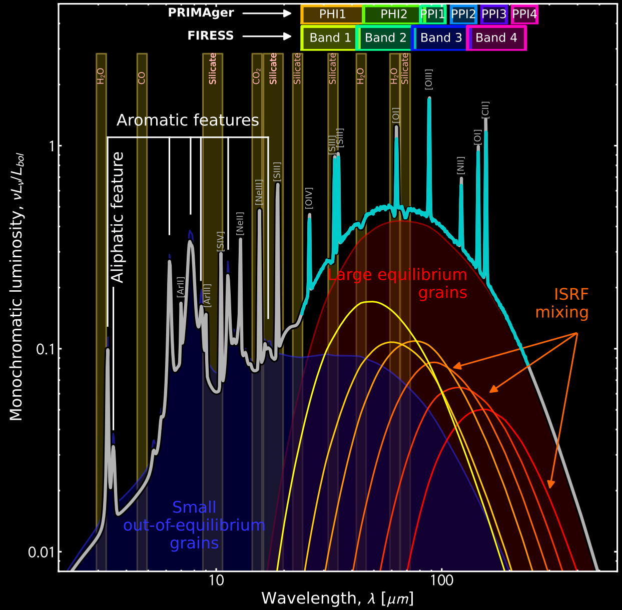


Deep MIR-to-FIR medium-resolution spectroscopy

$\Rightarrow$ No full-range IR spectrometer since ISOSWS/ISOLWS

- Constrain silicate crystallinity
- Look for various oxides
- Full study of ice mantles

Science Case | Surveying the Mineralogical Diversity of the ISM

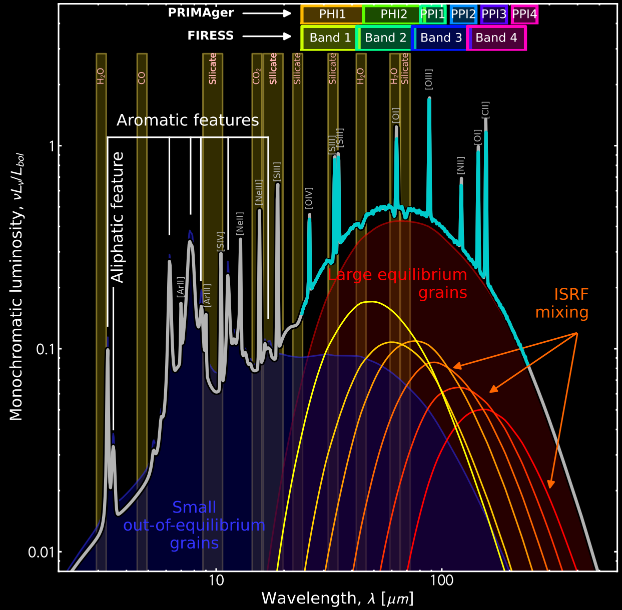


Deep MIR-to-FIR medium-resolution spectroscopy

⇒ No full-range IR spectrometer since ISOSWS/ISOLWS

- Constrain silicate crystallinity
- Look for various oxides
- Full study of ice mantles

⇒ need a direct constraint on the grain constitution



Deep MIR-to-FIR medium-resolution spectroscopy

$\Rightarrow$ No full-range IR spectrometer since ISOSWS/ISOLWS

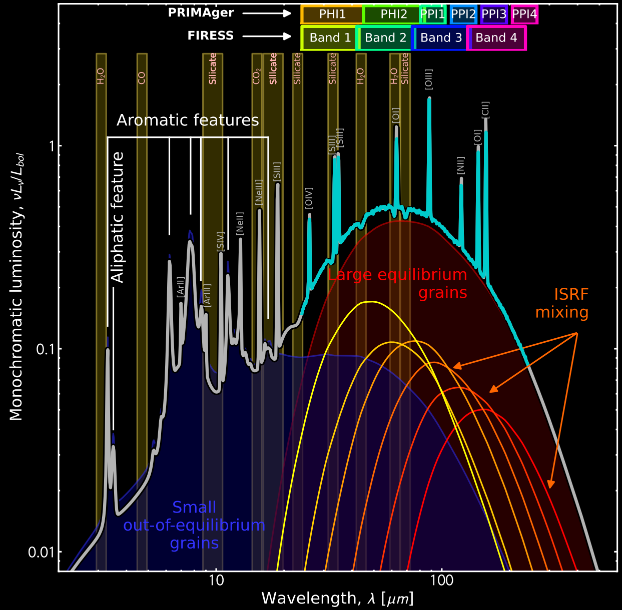
- Constrain silicate crystallinity
- Look for various oxides
- Full study of ice mantles

$\Rightarrow$ need a direct constraint on the grain constitution

Possible FIRESS strategy

$20' \times 20'$ maps at $R \simeq 150$

Science Case | Surveying the Mineralogical Diversity of the ISM



Deep MIR-to-FIR medium-resolution spectroscopy

⇒ No full-range IR spectrometer since ISOSWS/ISOLWS

- Constrain silicate crystallinity
- Look for various oxides
- Full study of ice mantles

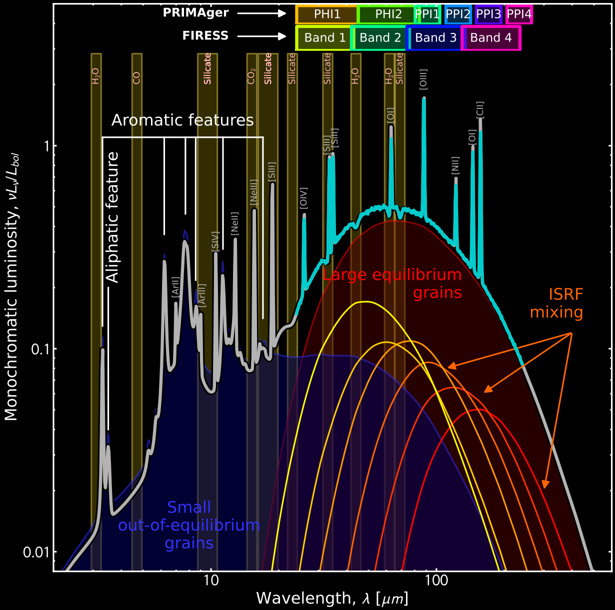
⇒ need a direct constraint on the grain constitution

Possible FIRESS strategy

$20' \times 20'$ maps at $R \simeq 150$

LMC: 12 SF regions (180 h)

Science Case | Surveying the Mineralogical Diversity of the ISM



Deep MIR-to-FIR medium-resolution spectroscopy

⇒ No full-range IR spectrometer since ISOSWS/ISOLWS

- Constrain silicate crystallinity
- Look for various oxides
- Full study of ice mantles

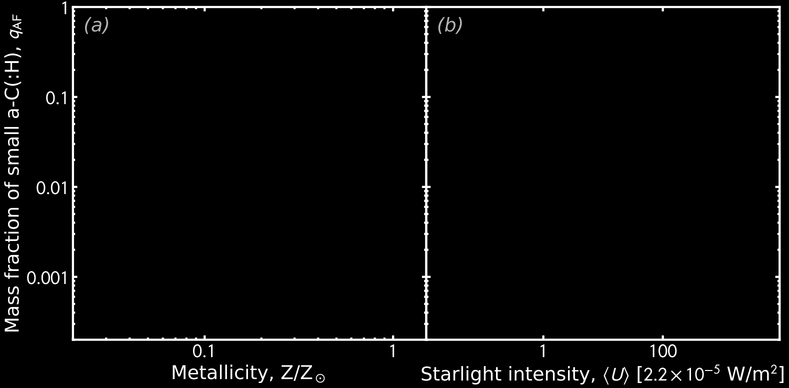
⇒ need a direct constraint on the grain constitution

Possible FIRESS strategy

$20' \times 20'$ maps at $R \simeq 150$

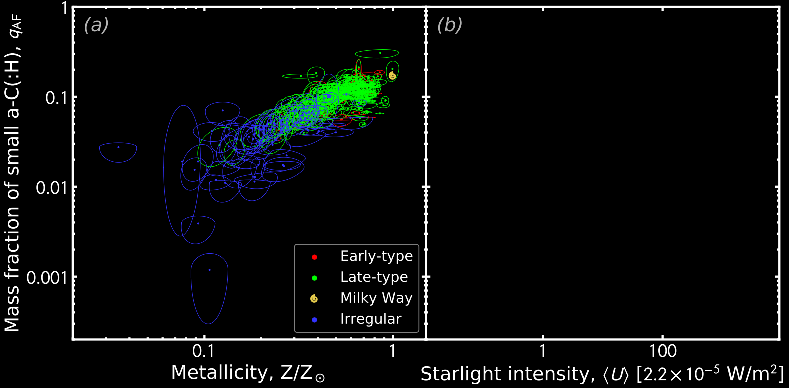
LMC: 12 SF regions (180 h)

SMC: 8 SF regions (748 h)

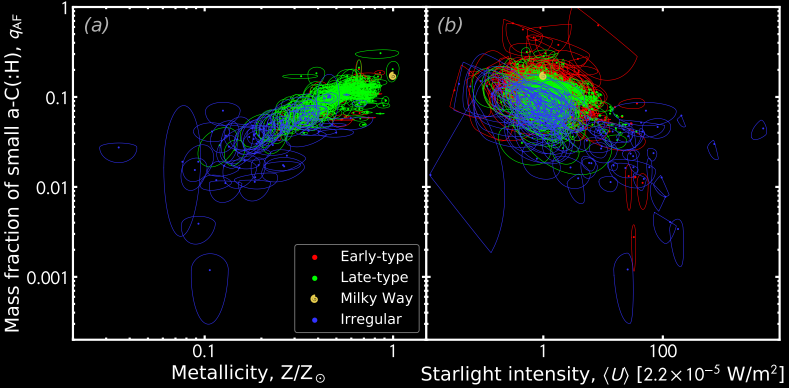


(Galliano et al., 2021)

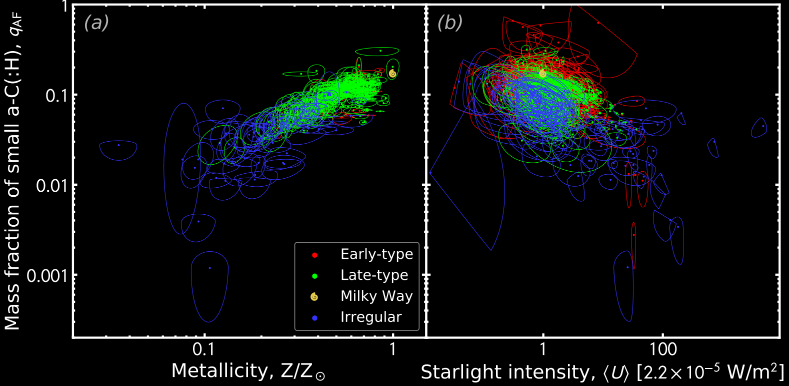
Science Case | Solving the Star-Formation – Metallicity Degeneracy



(Galliano et al., 2021)



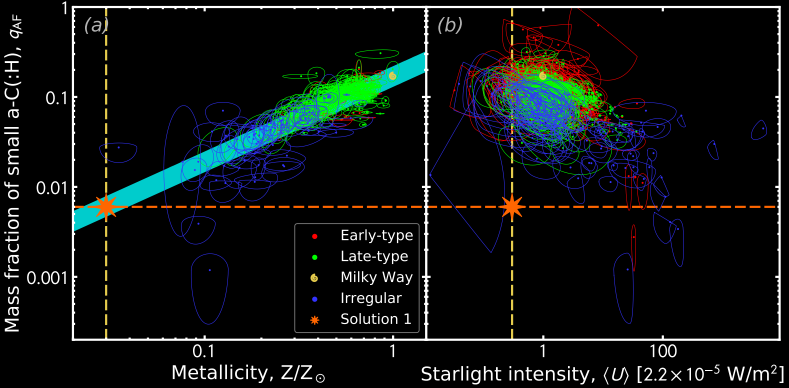
(Galliano et al., 2021)



(Galliano et al., 2021)

Quiescent low-metallicity galaxies

Necessary to solve the degeneracy



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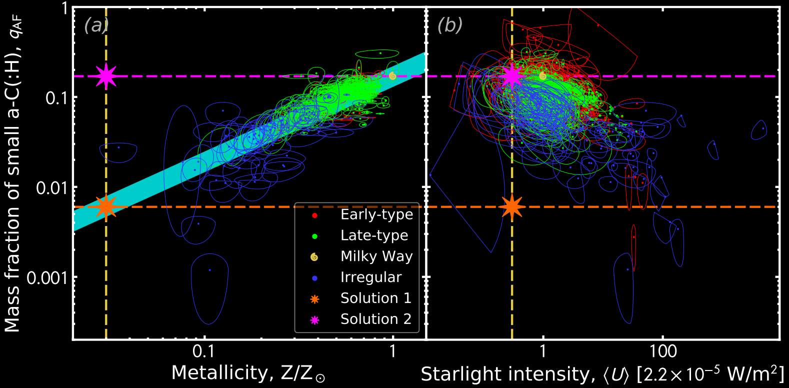
Quiescent low-metallicity galaxies

Necessary to solve the degeneracy



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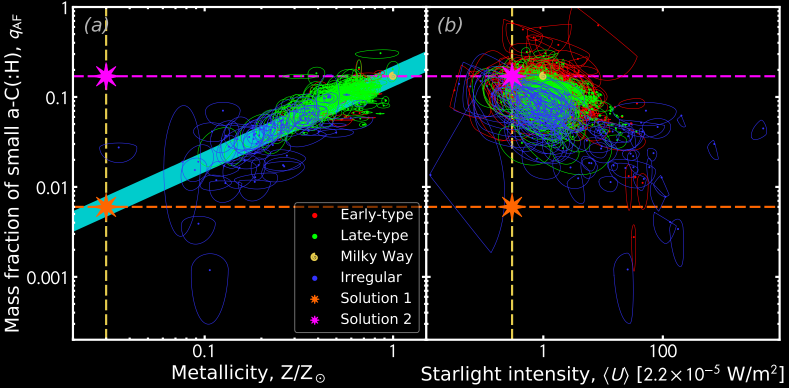
Quiescent low-metallicity galaxies

Necessary to solve the degeneracy

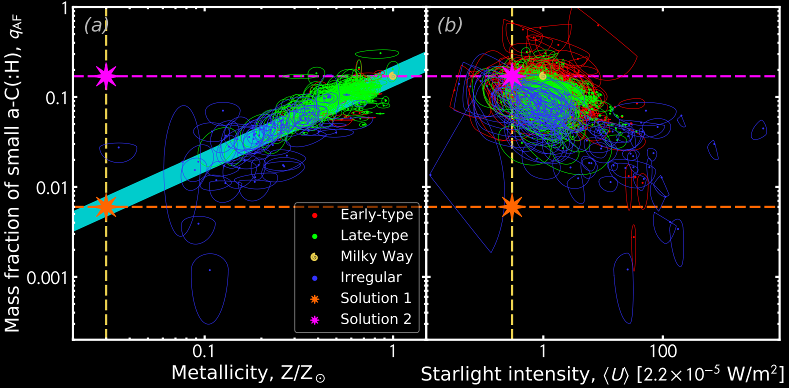
Science Case | Solving the Star-Formation – Metallicity Degeneracy



(Galliano et al., 2021)

Quiescent low-metallicity galaxies

Necessary to solve the degeneracy → not detected in the IR



(Galliano et al., 2021)

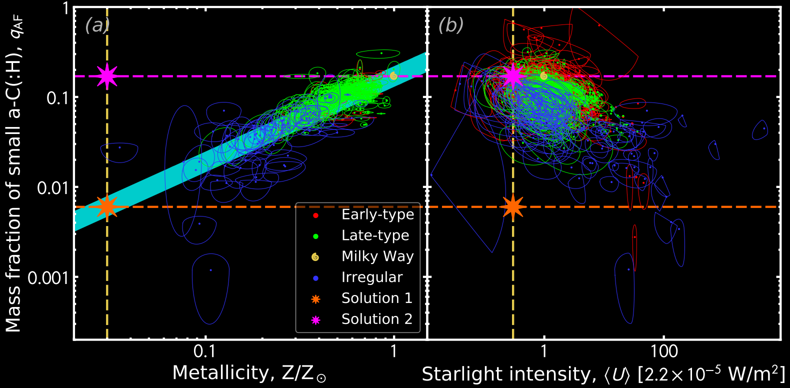
Quiescent low-metallicity galaxies

Necessary to solve the degeneracy → not detected in the IR

Possible Observing Strategy

$2' \times 2'$ maps of 100 local low-Z galaxies.

Science Case | Solving the Star-Formation – Metallicity Degeneracy



(Galliano et al., 2021)

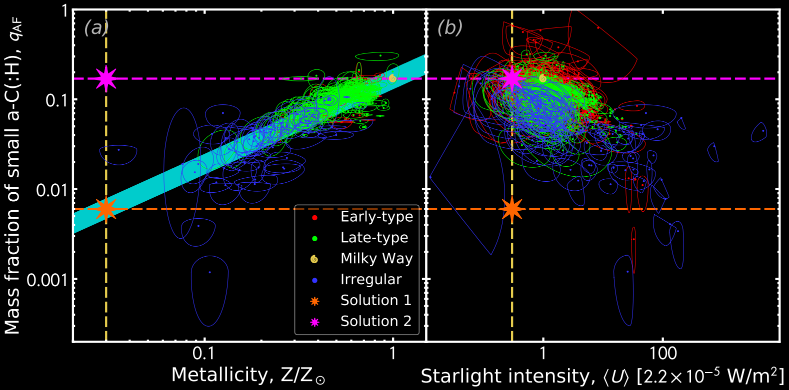
Quiescent low-metallicity galaxies

Necessary to solve the degeneracy → not detected in the IR

Possible Observing Strategy

$2' \times 2'$ maps of 100 local low-Z galaxies.

PRIMAger: PHI1–PPI4 (31 h)



(Galliano et al., 2021)

Quiescent low-metallicity galaxies

Necessary to solve the degeneracy $\rightarrow$ not detected in the IR

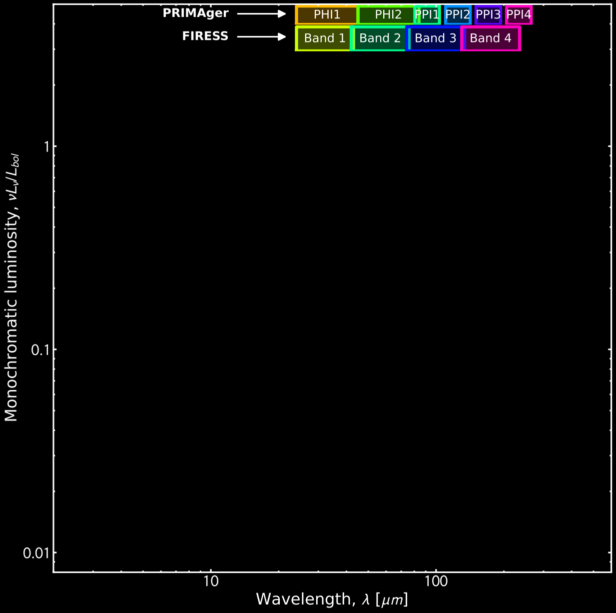
Possible Observing Strategy

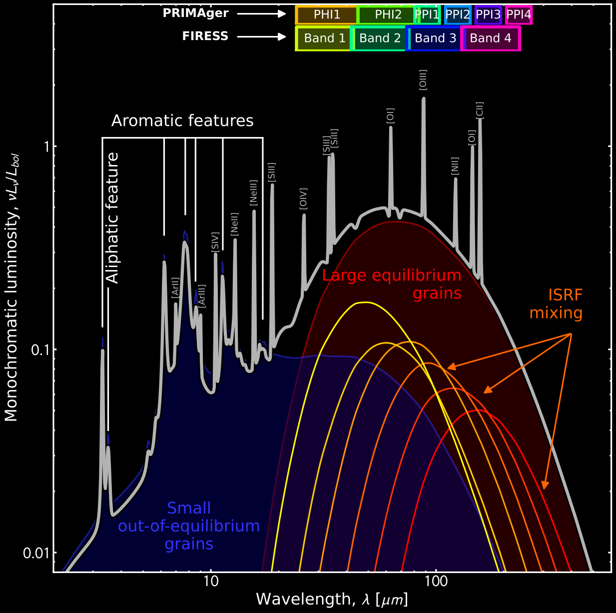
$2' \times 2'$ maps of 100 local low-Z galaxies.

PRIMAger: PHI1–PPI4 (31 h)

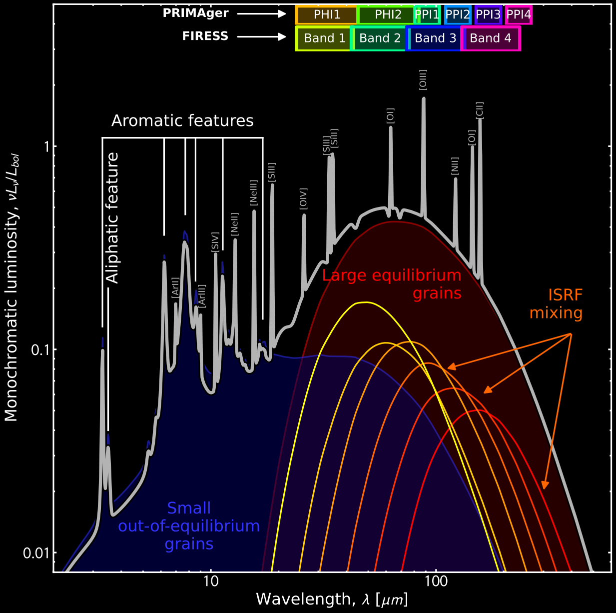
FIRESS: bands 2–4 (97 h)

Science Case | Constraining a Gas & Dust Multiphase Model

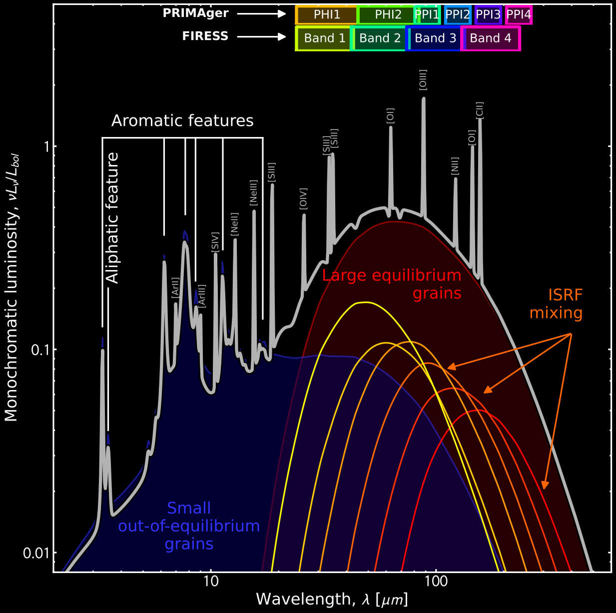



PRIMAger
FIRESS
PHI1
PHI2
PPI1
PPI2
PPI3
PPI4
Band 1
Band 2
Band 3
Band 4
Aromatic features
Aliphatic feature
[ArII]
[ArIII]
[SIV]
[NeII]
[NeIII]
[SIII]
[OIV]
[SIII]
[SiII]
[OI]
[OIII]
[NII]
[OI]
[CII]
Large equilibrium grains
ISRF mixing
Small out-of-equilibrium grains
Monochromatic luminosity, $\nu L_\nu / L_{bol}$
Wavelength, λ [μm]
1
0.1
0.01
10
100

Science Case | Constraining a Gas & Dust Multiphase Model

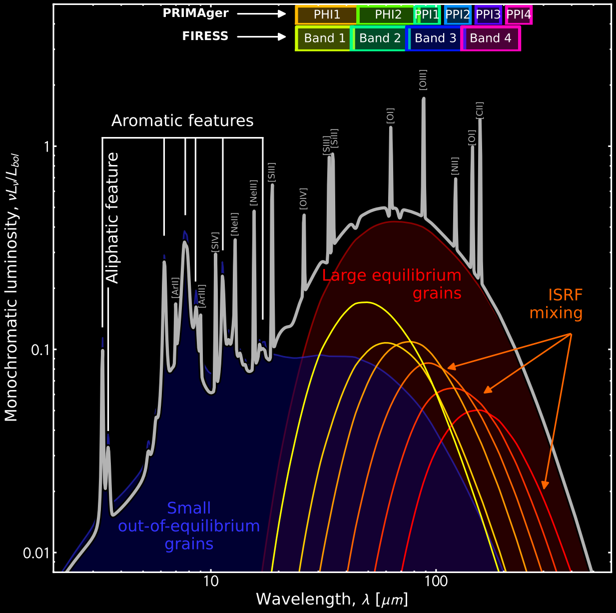


Simultaneous IR photometry & spectroscopy



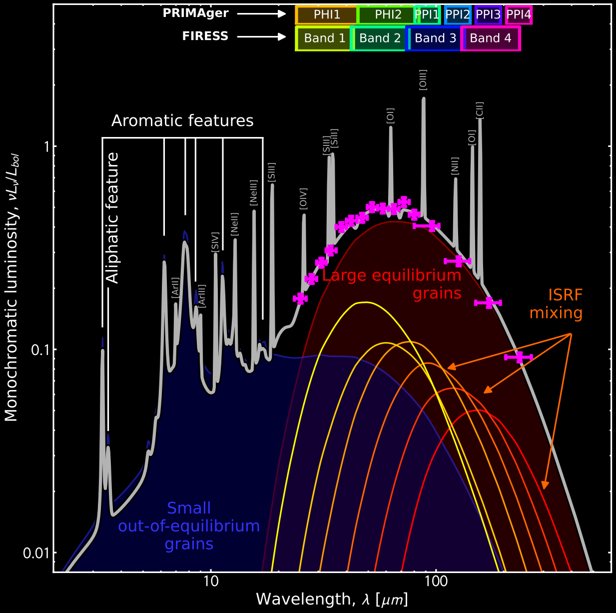
Simultaneous IR photometry & spectroscopy

- Multiphase decomposition $\Rightarrow$ dust continuum & line intensity in the same region



Simultaneous IR photometry & spectroscopy

- Multiphase decomposition ⇒ dust continuum & line intensity in the same region
- Break the degeneracy b/w dust properties & ISM topology



Simultaneous IR photometry & spectroscopy

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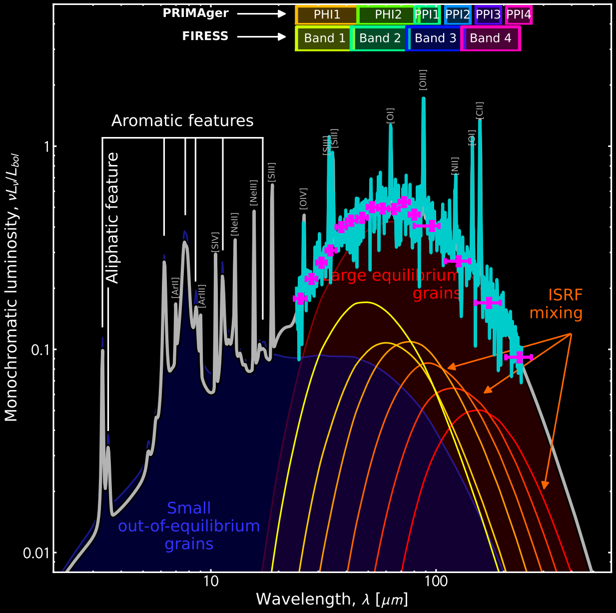

Simultaneous IR photometry & spectroscopy

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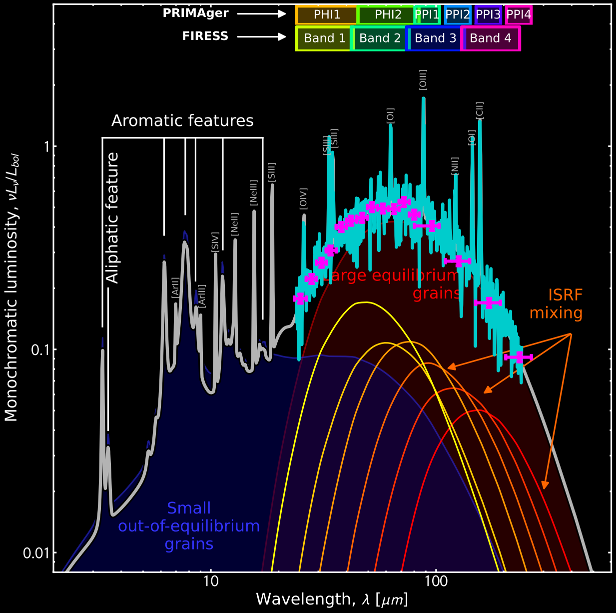


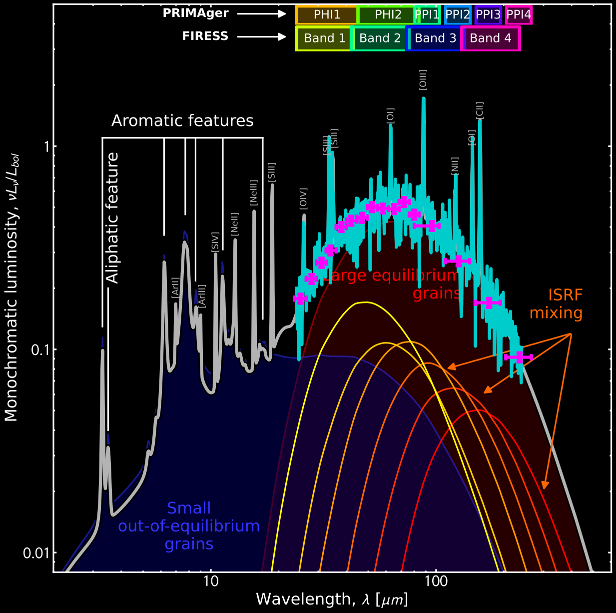
Simultaneous IR photometry & spectroscopy

- Multiphase decomposition $\Rightarrow$ dust continuum & line intensity in the same region
- Break the degeneracy b/w dust properties & ISM topology

Possible Observing Strategy

30 disk & 100 low-Z galaxies

Science Case | Constraining a Gas & Dust Multiphase Model



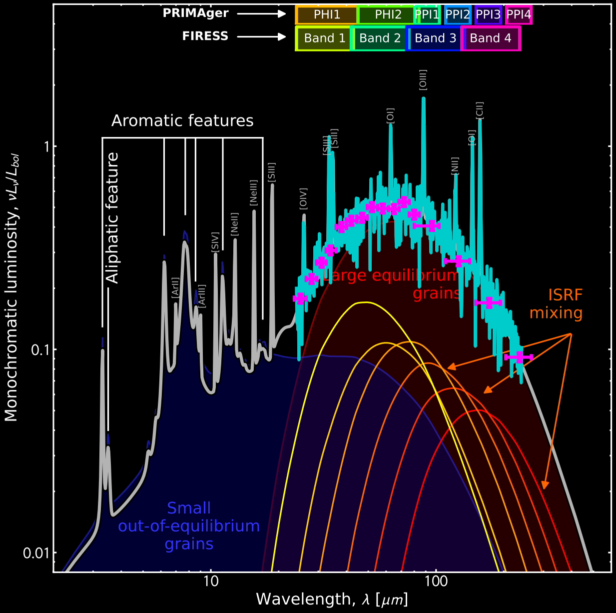
Simultaneous IR photometry & spectroscopy

- Multiphase decomposition $\Rightarrow$ dust continuum & line intensity in the same region
- Break the degeneracy b/w dust properties & ISM topology

Possible Observing Strategy

30 disk & 100 low-Z galaxies

PRIMAger: PHI1–PPI4 (854 h)



Simultaneous IR photometry & spectroscopy

- Multiphase decomposition $\Rightarrow$ dust continuum & line intensity in the same region
- Break the degeneracy b/w dust properties & ISM topology

Possible Observing Strategy

30 disk & 100 low-Z galaxies

PRIMAger: PHI1–PPI4 (854 h)

FIRESS: bands 1–4 $R \simeq 150$ (5 h)

These slides

What we will be able to achieve with a few PRIMA large programs

These slides

What we will be able to achieve with a few PRIMA large programs

1. Deep maps of the diffuse ISM of L(S)MC $\Rightarrow$ extragalactic dust models

These slides

What we will be able to achieve with a few PRIMA large programs

1. Deep maps of the diffuse ISM of L(S)MC $\Rightarrow$ extragalactic dust models
2. Mineralogy of SF regions $\Rightarrow$ better understanding of grain composition

These slides

Conclusion | Summary

What we will be able to achieve with a few PRIMA large programs

1. Deep maps of the diffuse ISM of L(S)MC $\Rightarrow$ extragalactic dust models
2. Mineralogy of SF regions $\Rightarrow$ better understanding of grain composition
3. Detect quiescent low-Z $\Rightarrow$ understand the role of metallicity

These slides

What we will be able to achieve with a few PRIMA large programs

1. Deep maps of the diffuse ISM of L(S)MC $\Rightarrow$ extragalactic dust models
2. Mineralogy of SF regions $\Rightarrow$ better understanding of grain composition
3. Detect quiescent low-Z $\Rightarrow$ understand the role of metallicity
4. Dust & gas simultaneous modeling $\Rightarrow$ multiphase dust properties

These slides

What we will be able to achieve with a few PRIMA large programs

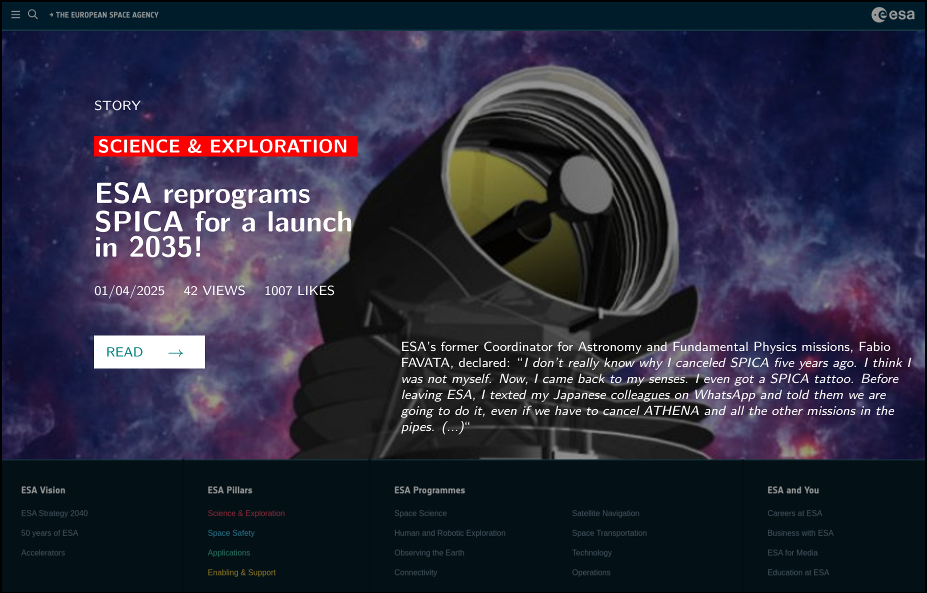
1. Deep maps of the diffuse ISM of L(S)MC ⇒ extragalactic dust models
2. Mineralogy of SF regions ⇒ better understanding of grain composition
3. Detect quiescent low-Z ⇒ understand the role of metallicity
4. Dust & gas simultaneous modeling ⇒ multiphase dust properties

These slides

Look out for the upcoming JATIS paper (accepted yesterday)

The PRIMA promise of deciphering interstellar dust evolution with observations of the nearby Universe

Frédéric Galliano[a,*], Maarten Baes[b], Léo Belloir[a], Simone Bianchi[c], Caroline Bot[d], Francesco Calura[e], Viviana Casasola[e], Jérémy Chastenet[b], Christopher Clark[f], Lucie Correia[d], Ilse de Looze[b], Mika Juvela[g], Hidehiro Kaneda[h], Stavroula Katsioli[i], Francisca Kemper[j,k,l], Vianney Lebouteiller[a], Suzanne Madden[a], Mikako Matsuura[m], Takashi Onaka[n], Lara Pantoni[b], Francesca Pozzi[e], Monica Relaño Pastor[o], Marc Sauvage[a], Matthew Smith[m], Vidhi Tailor[e], Tsutomu T. Takeuchi[p,q], Emmanuel Xilouris[i], Nathalie Ysard[r]


THE EUROPEAN SPACE AGENCY
esa
STORY
SCIENCE & EXPLORATION
ESA reprograms SPICA for a launch in 2035!
01/04/2025 42 VIEWS 1007 LIKES
READ →
ESA's former Coordinator for Astronomy and Fundamental Physics missions, Fabio FAVATA, declared: "*I don't really know why I canceled SPICA five years ago. I think I was not myself. Now, I came back to my senses. I even got a SPICA tattoo. Before leaving ESA, I texted my Japanese colleagues on WhatsApp and told them we are going to do it, even if we have to cancel ATHENA and all the other missions in the pipes. (...)*"
ESA Vision
ESA Strategy 2040
50 years of ESA
Accelerators
ESA Pillars
Science & Exploration
Space Safety
Applications
Enabling & Support
ESA Programmes
Space Science
Human and Robotic Exploration
Observing the Earth
Connectivity
Satellite Navigation
Space Transportation
Technology
Operations
ESA and You
Careers at ESA
Business with ESA
ESA for Media
Education at ESA

Third 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, Andrea BRACCO, Pierre CHAINAIS, Emma CURTIS LAKE, Emmanuel DARTOIS, Éric EMSELLEM, 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.

Conclusion | The Dusty Universe 2025 Conference

The Fifth Pan Dust Conference: November 10 – 14, 2025 – University of Arizona, Tucson

Scope: all aspects of dust investigations including observations, theory, modeling, and laboratory studies.

Expected attendance: $\gtrsim$ 200 participants.

Past meetings: 2003: Estes Park, Colorado; 2008: Heidelberg, Germany; 2013: Taipei, Taiwan; 2018: Copenhagen, Denmark.

More info: https://pandust2025.sciencesconf.org.

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