Estimating the dust-heating interstellar radiation field in nearby galaxies using the PHANGS surveys

By R.Maris, J.-Ph.Bernard, A.Hughes
IRAP, Université de Toulouse, CNRS, CNES, UPS, (Toulouse), France

PCMI Bordeaux, 28th of October 2024

The PHANGS surveys

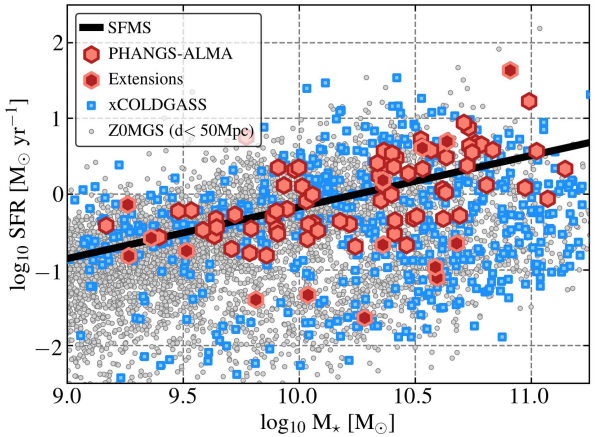
PHANGS galaxy sample :

(i) Parent sample of 90 ALMA-accessible galaxies

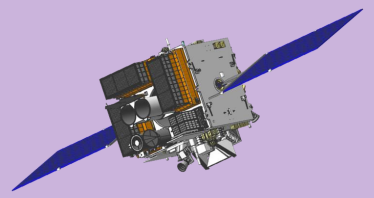
(ii) Nearby : D≤20 Mpc (1” ~ 100pc)

(iii) Face-on : inclination <75°

(iv) Stellar mass between 9.5<logM*<11, SF main sequence



UV



Astrosat

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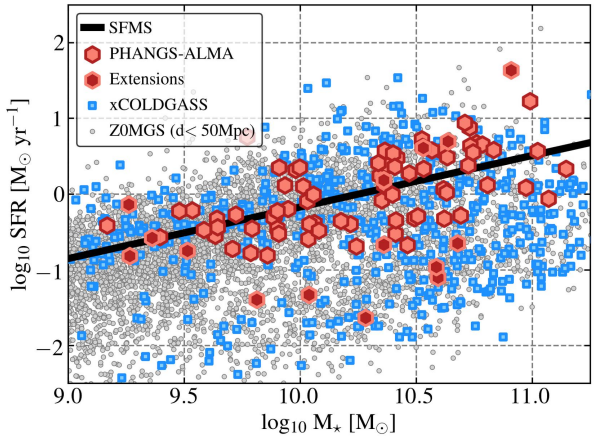
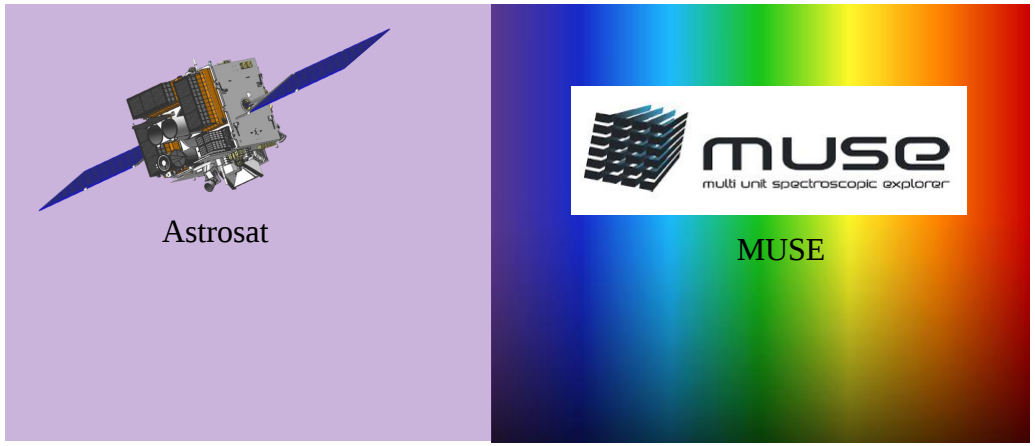


UV **Optical**



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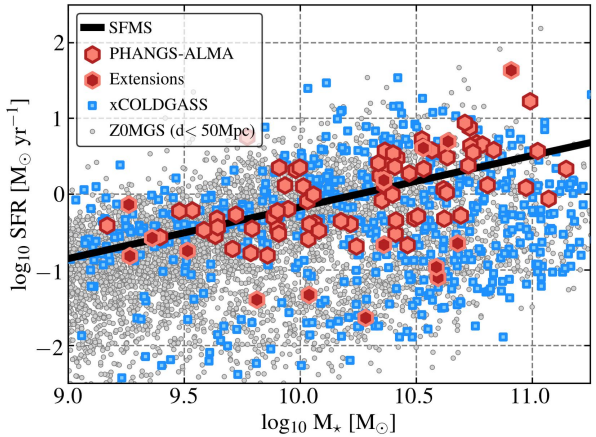

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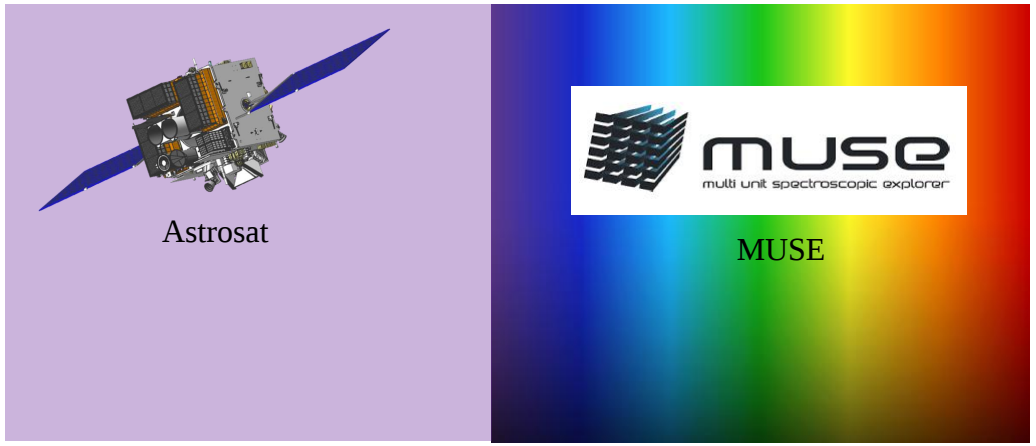

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UV +VIS

Used to estimate the *intensity* and *shape* of the ISRF

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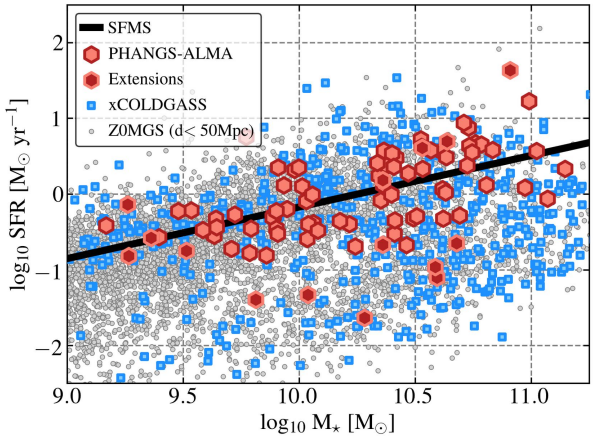
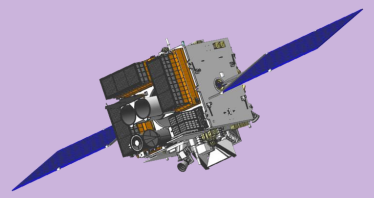


UV | **Optical** | **Near - Mid IR**



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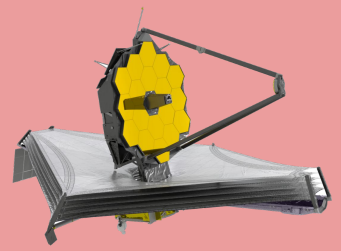

JWST

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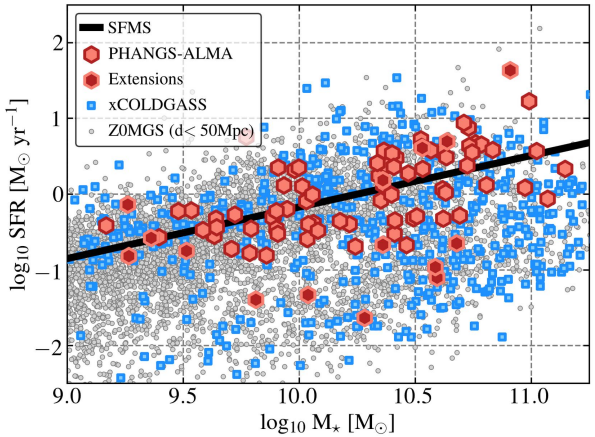
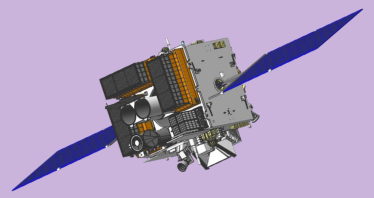


UV

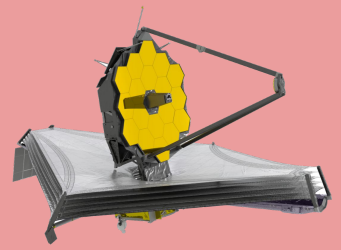


Astrosat

Optical

MUSE

Near - Mid IR



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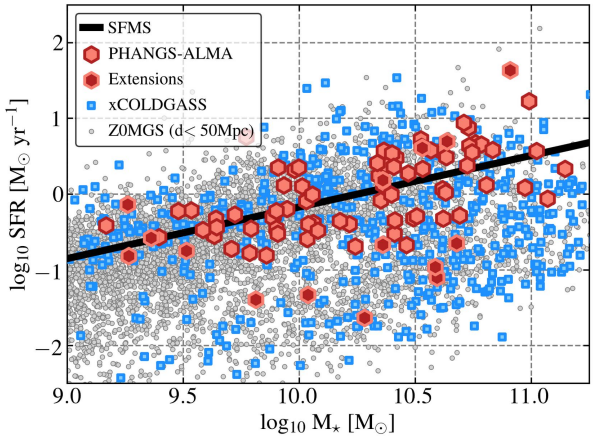

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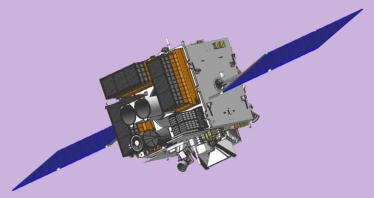
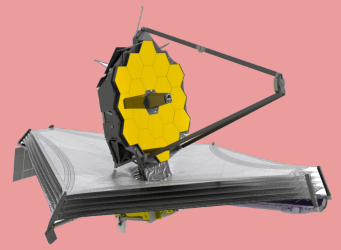


Astrosat

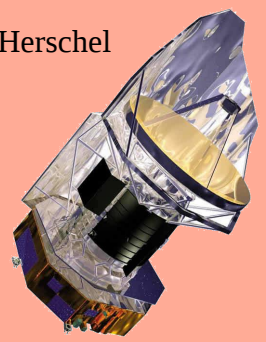
muse
multi unit spectroscopic explorer

MUSE



JWST

Herschel



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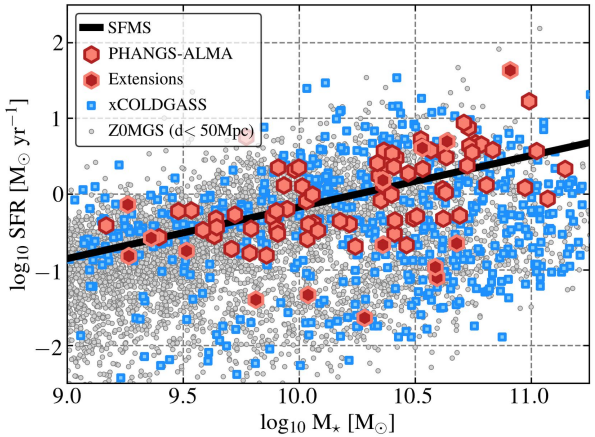

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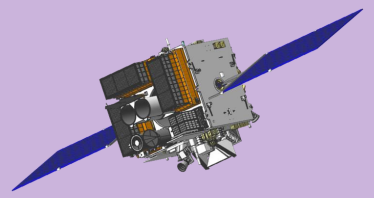

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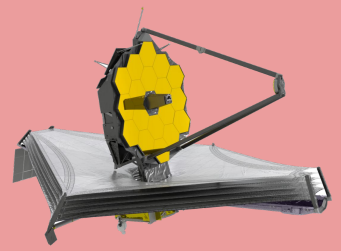
MUSE



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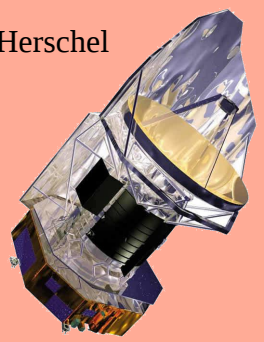

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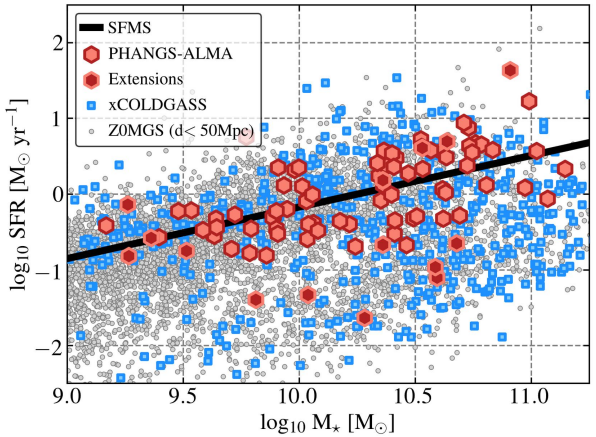
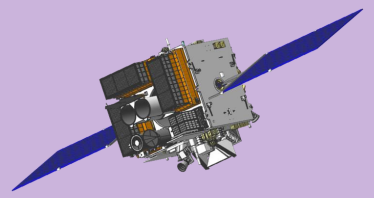


UV | **Optical** | **Near - Mid IR** | **Far IR** | **Radio**



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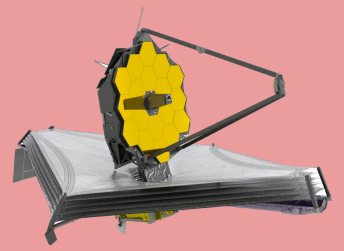

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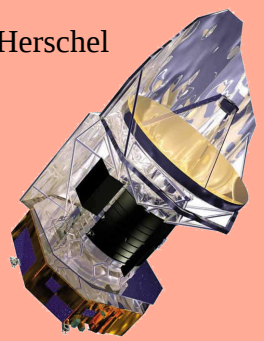
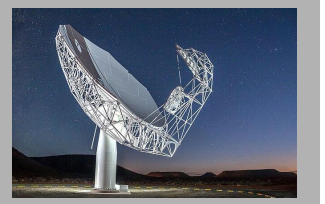


ALMA



Meerkat

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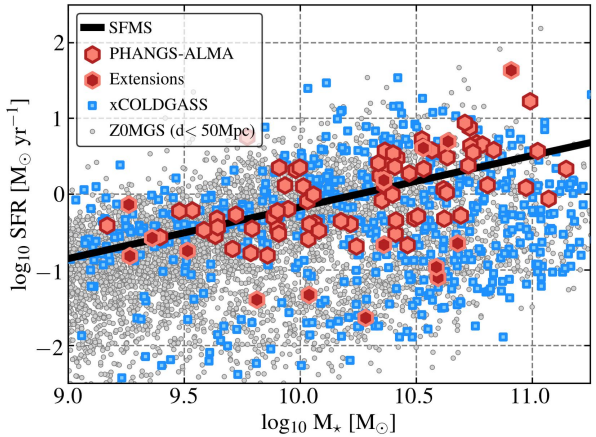

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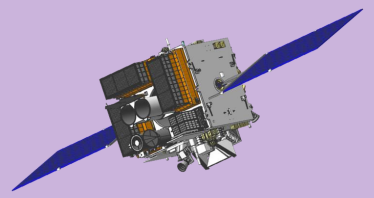
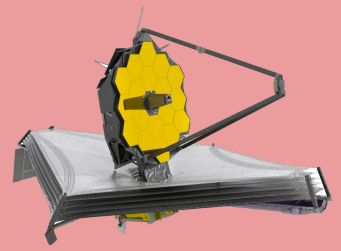


Astrosat

MUSE



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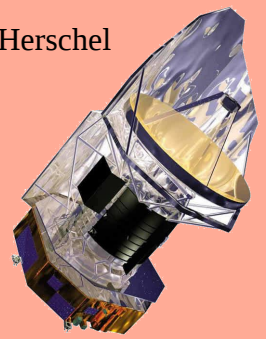
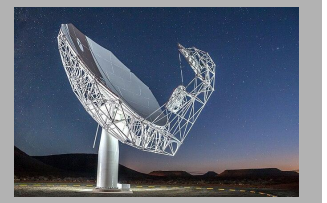


ALMA



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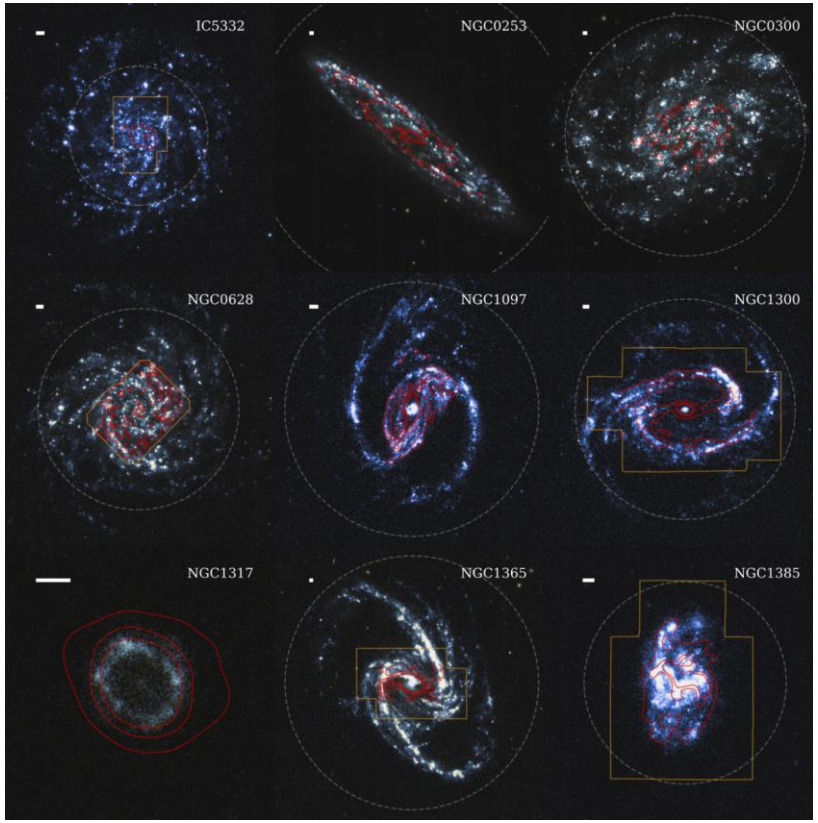
NIR + MIR
Used to estimate the PAH and VSG abundance

FIR
Used to estimate the *intensity* of the dust-heating ISRF

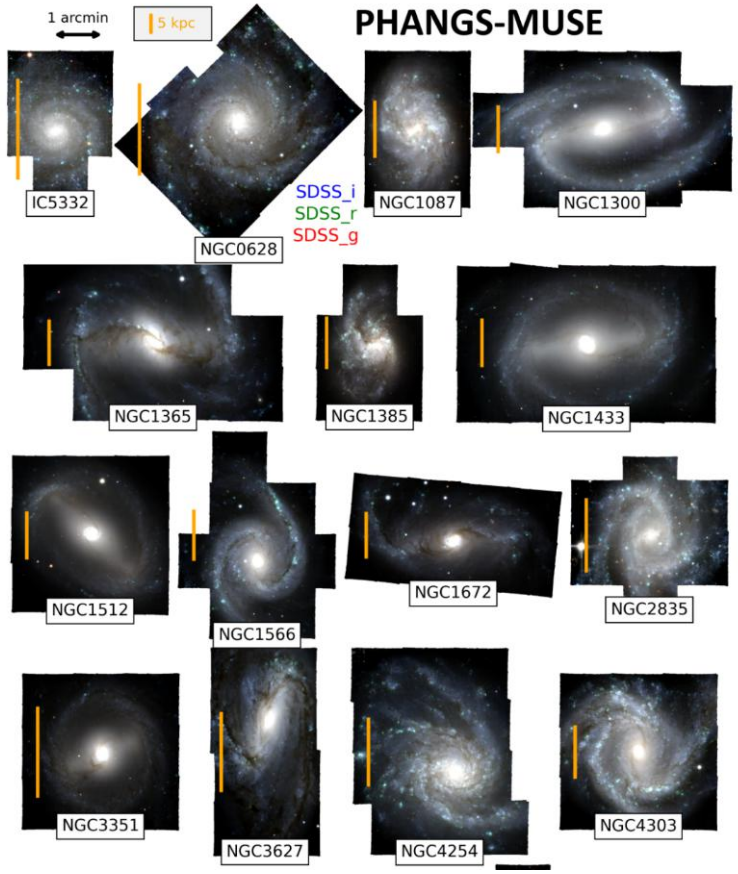
mm + radio
Used to estimate the gas column density NH

An empirical ISRF from UV+Optical+NIR SEDs

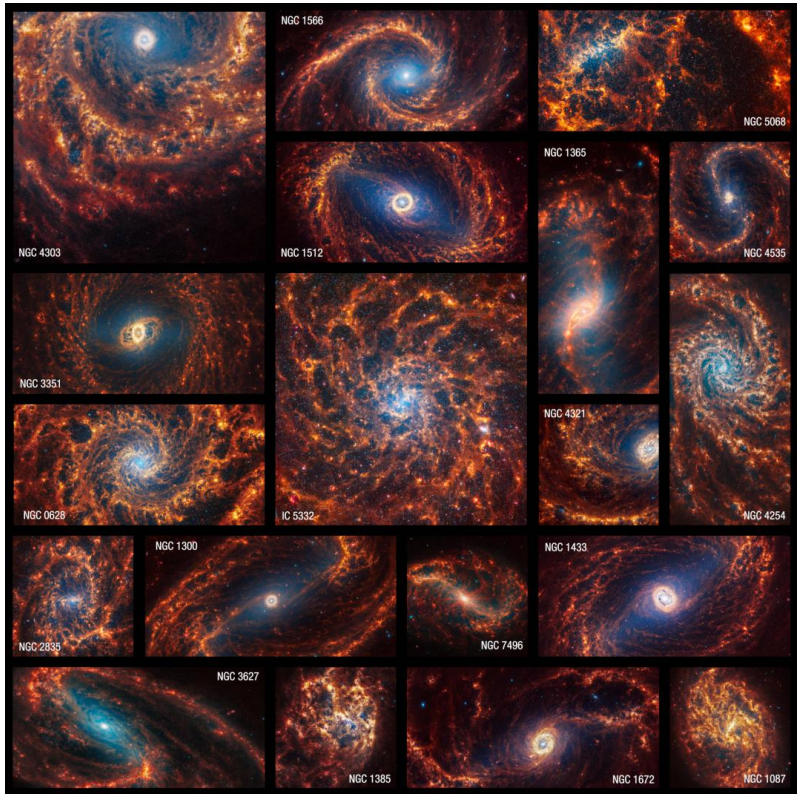
Astrosat (UV) res~1.5”



Muse (VIS) res~1”



JWST (NIR+MIR) res~1”



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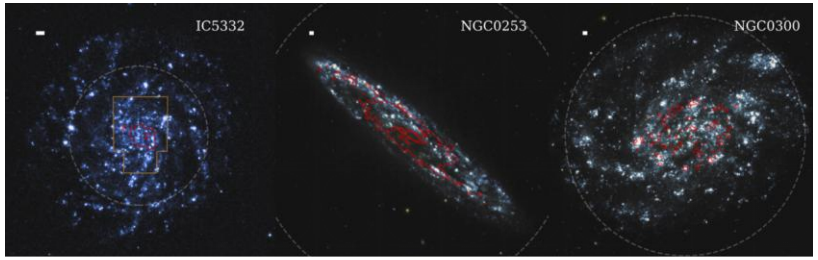
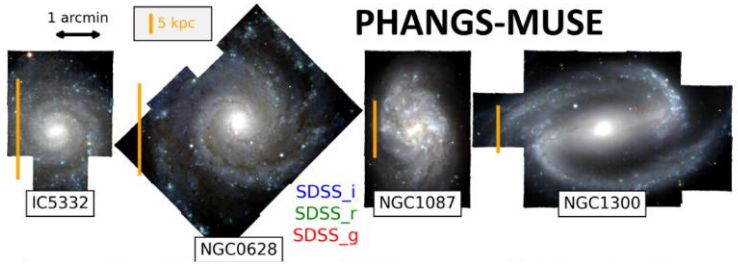


Muse (VIS) res~1”



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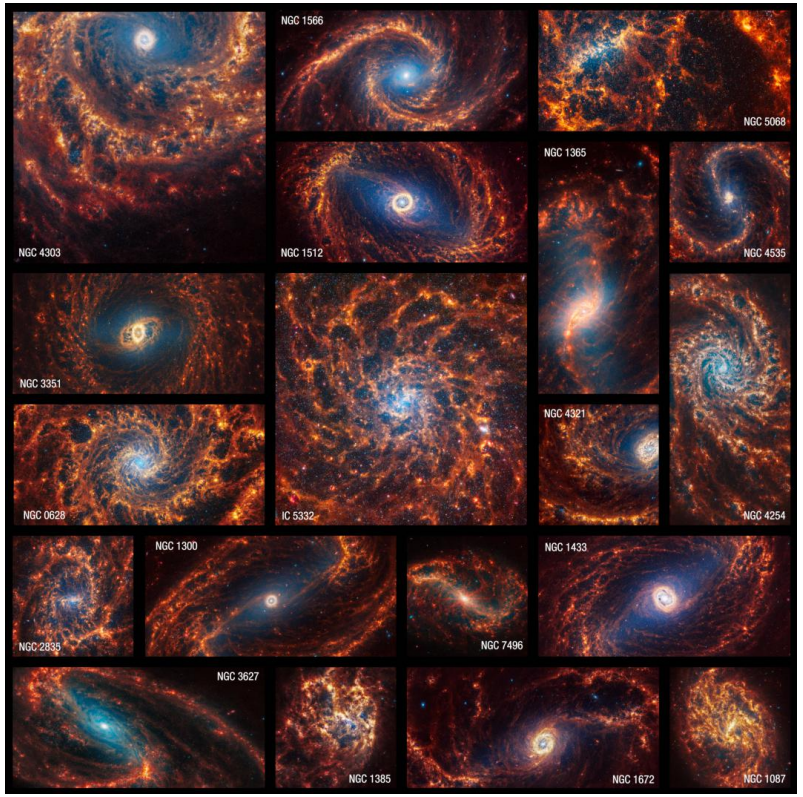

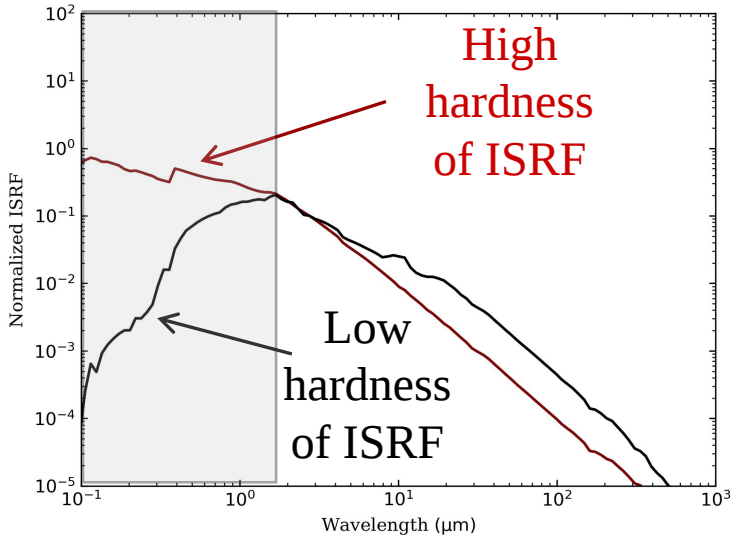

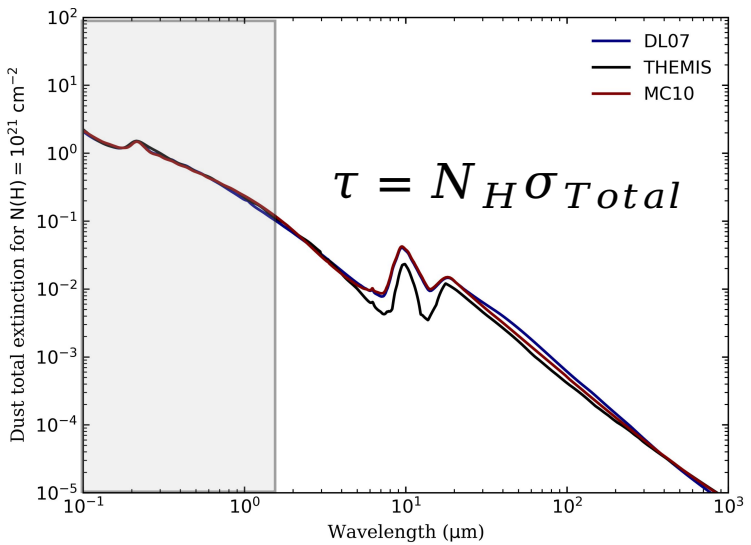

$E_{abs} \propto ISRF * \sigma_{Total}$ ⇒ ISRF change ⇒ E_{em} change ⇒ estimation of Y(dust) change

An empirical ISRF from UV+Optical+NIR SEDs

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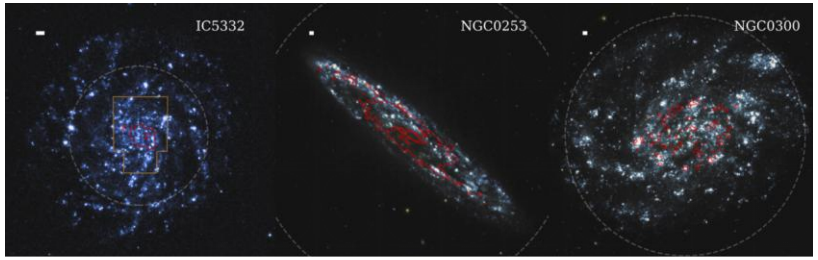
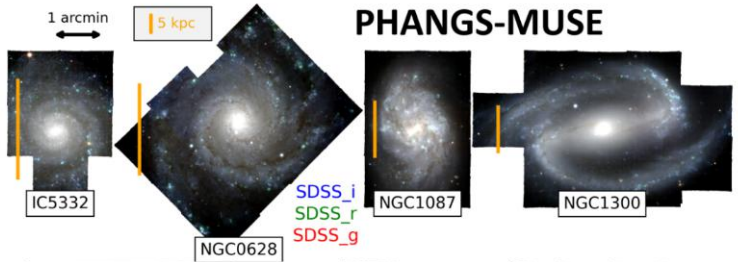


Muse (VIS) res~1”



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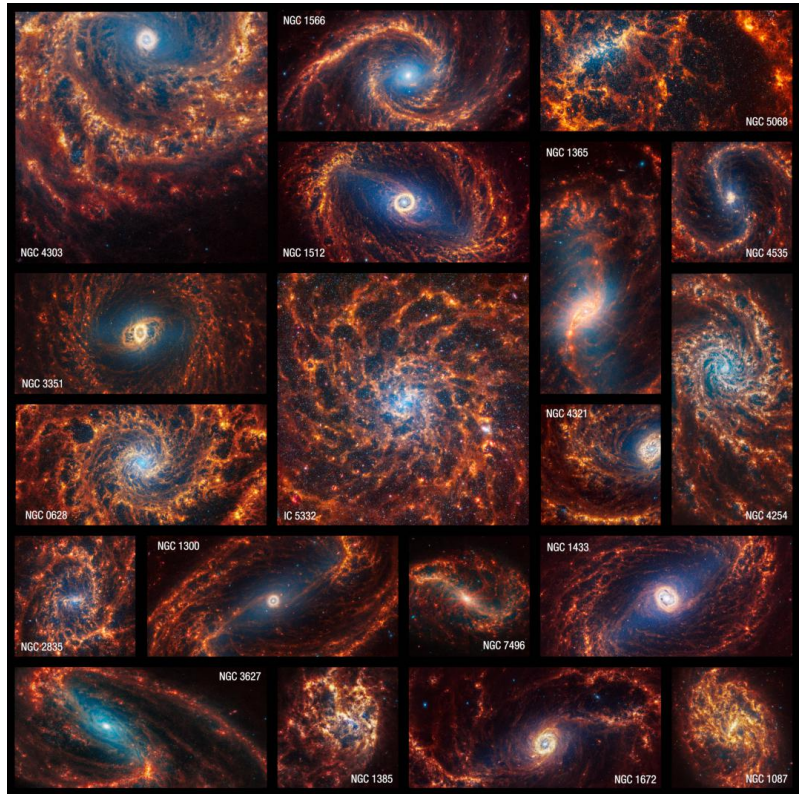

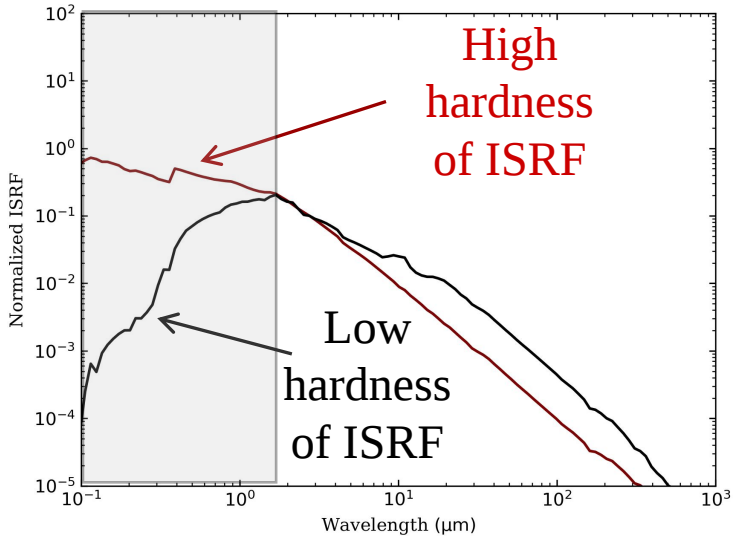

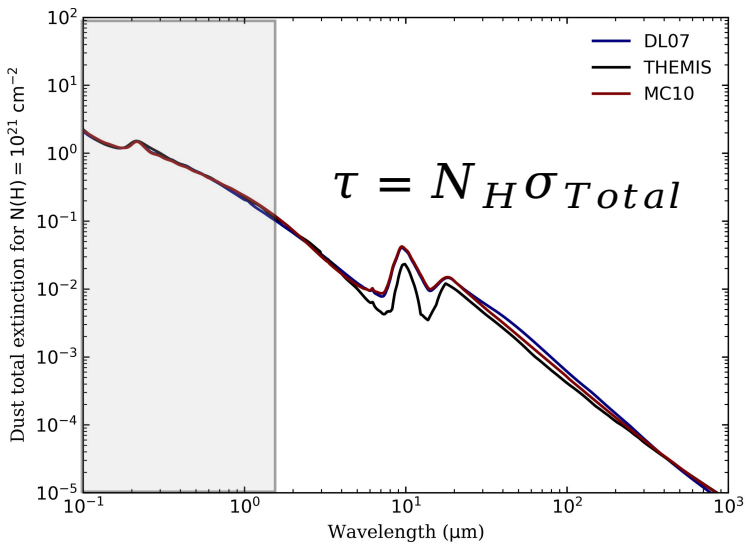

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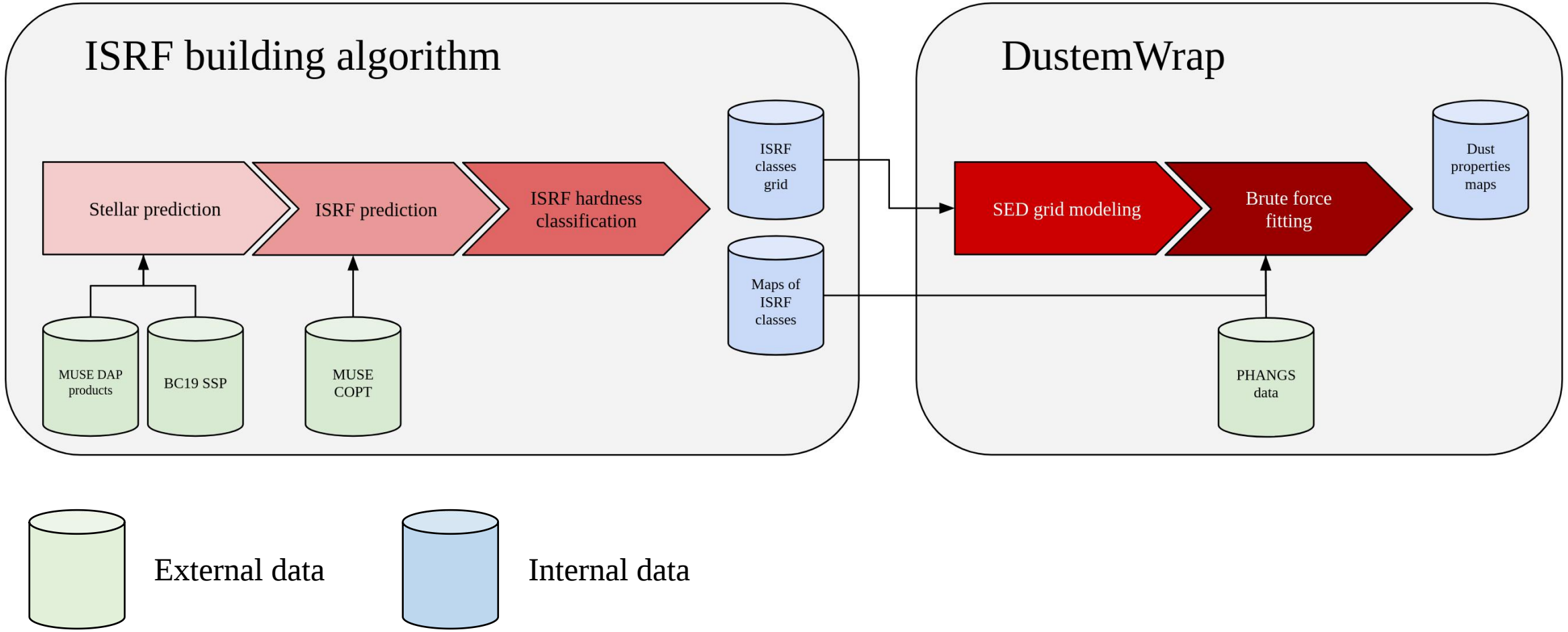
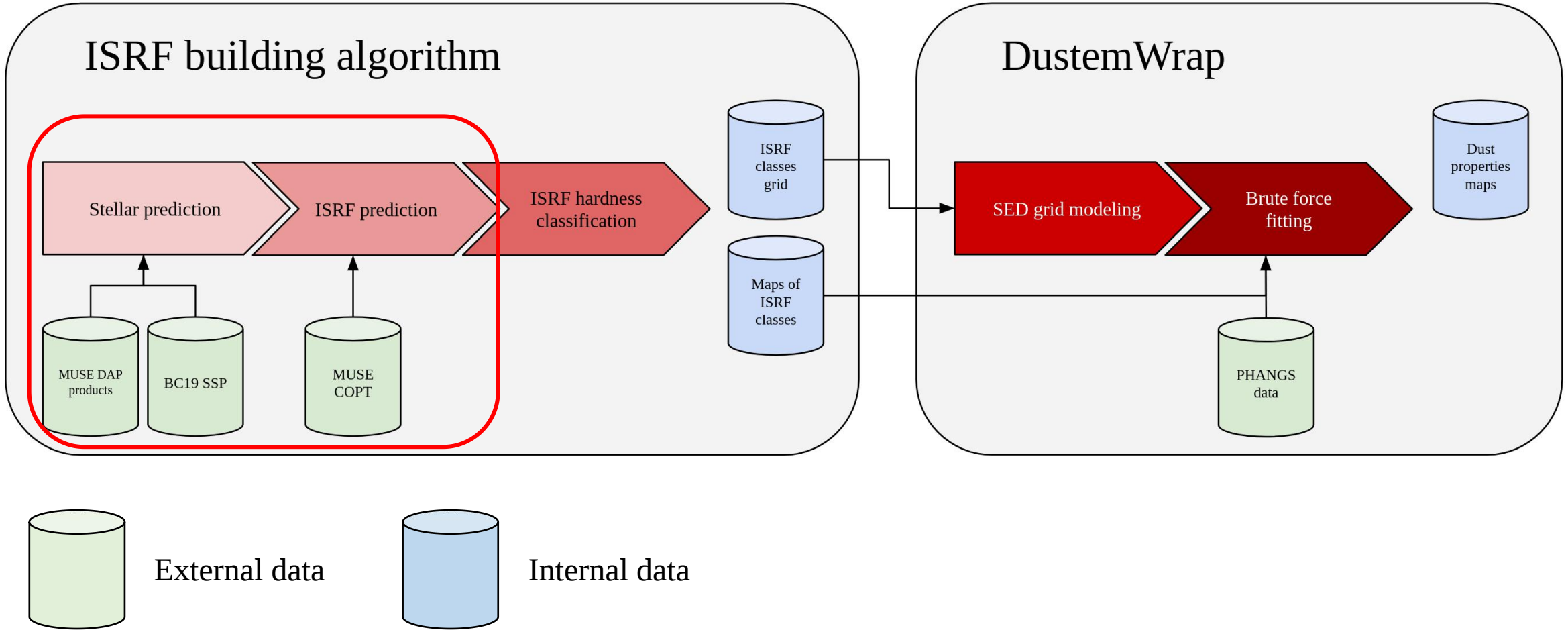
Issue : How do the predicted PAH abundances compare to estimate derived assuming the Mathis ISRF ?

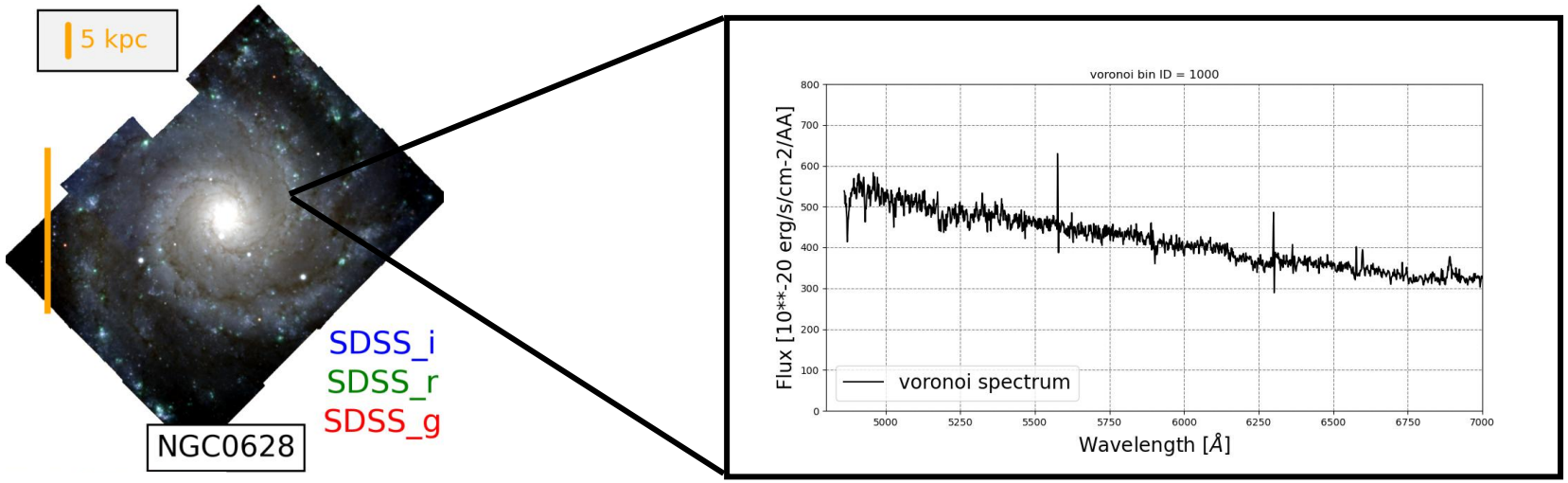
Method: chart overview



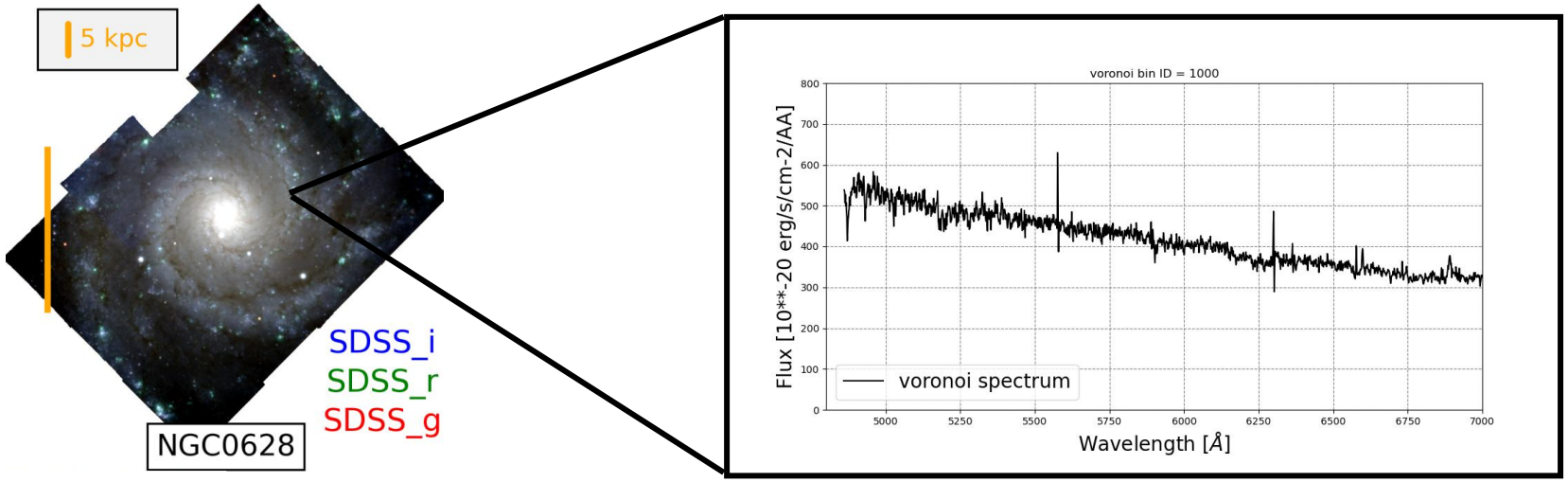
Building the empirical ISRFs



Stellar prediction

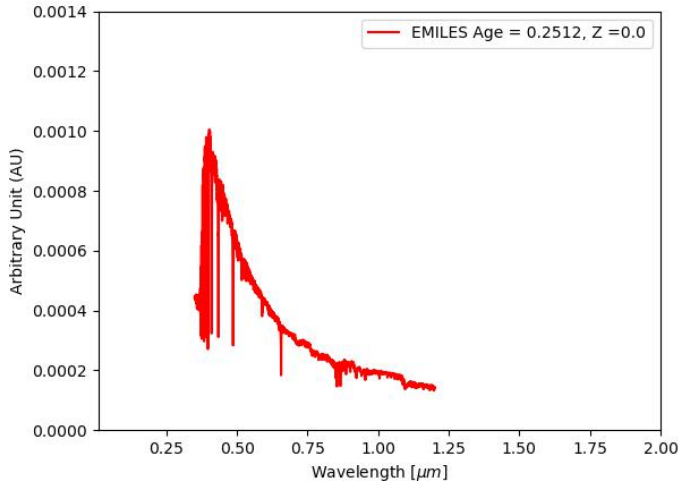


Stellar prediction



MUSE Data Analysis released is :

- The EMILES SSP templates with different age and metallicity Z
- The best-fitted weight wi of the SSPs
- Stellar prediction : $I_{\nu}^{*,unred} = \sum_{i}^{N} ssp_i w_i M_i^* / N_{pix}$



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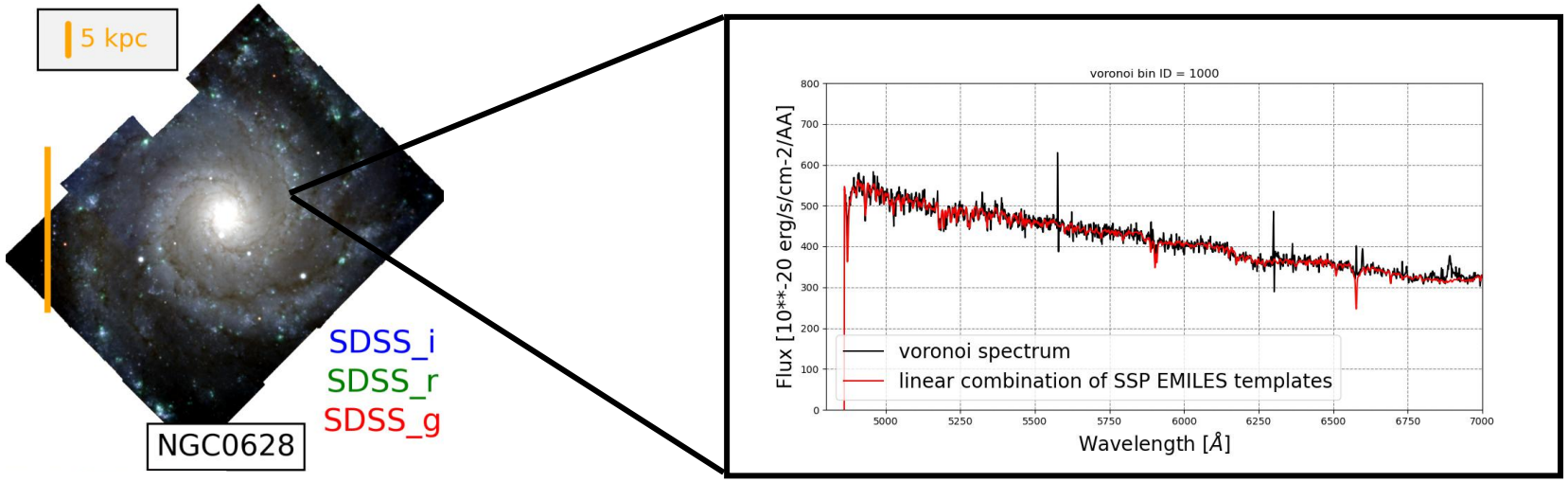

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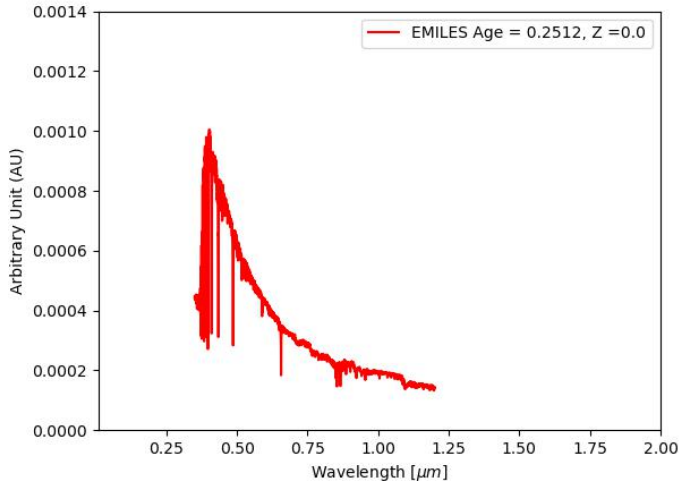
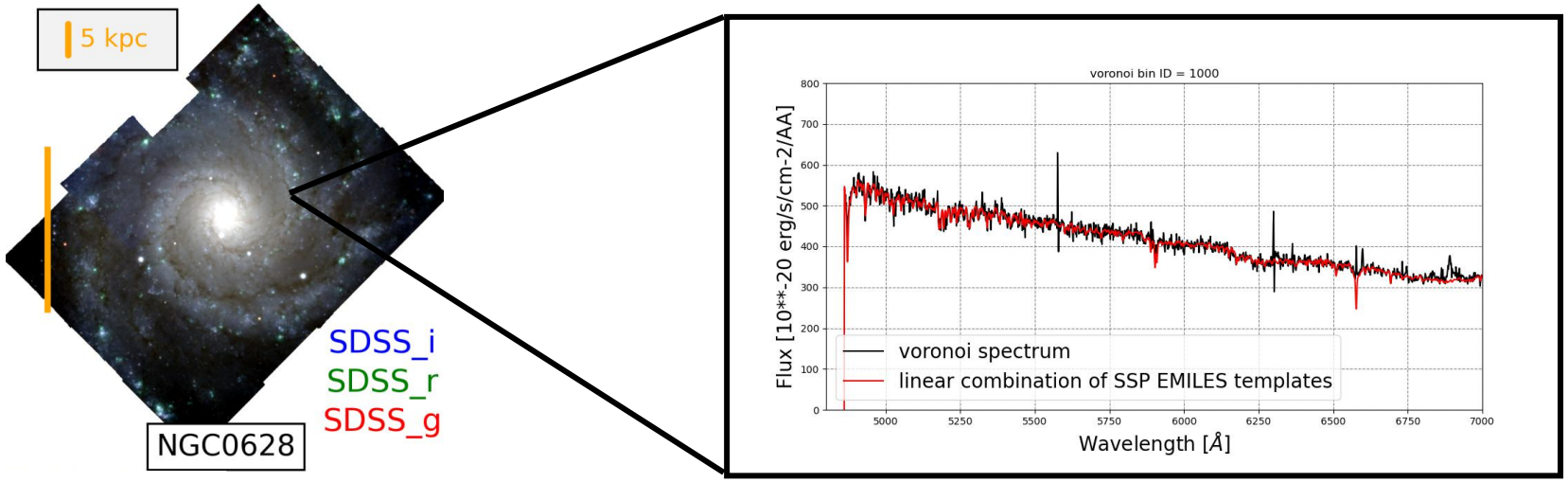


Stellar prediction



EMILES SSPs templates <=> **BC19s SSPs extanded in UV + IR** :

- The EMILES SSPs templates are high spectral resolution, but restricted wavelenght coverage
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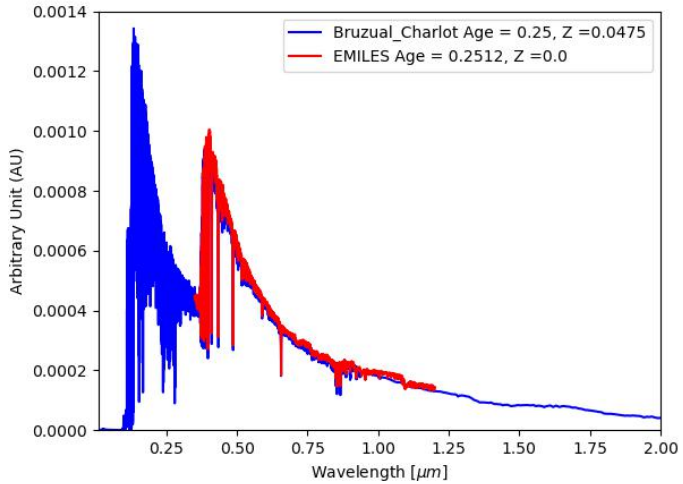
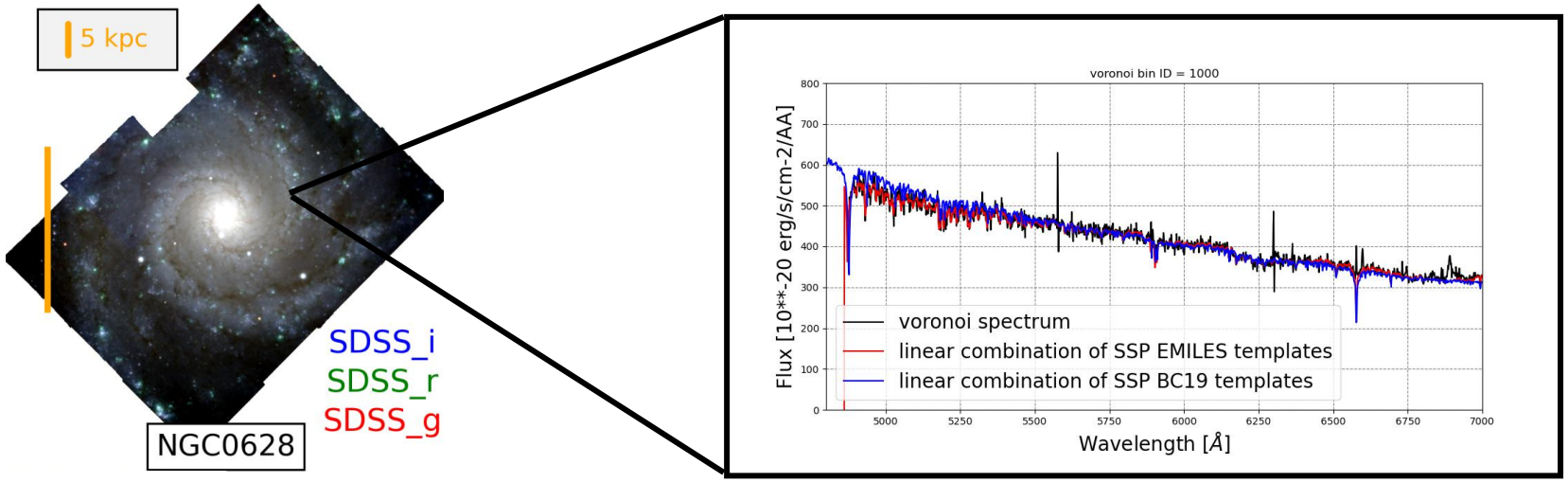


Stellar prediction



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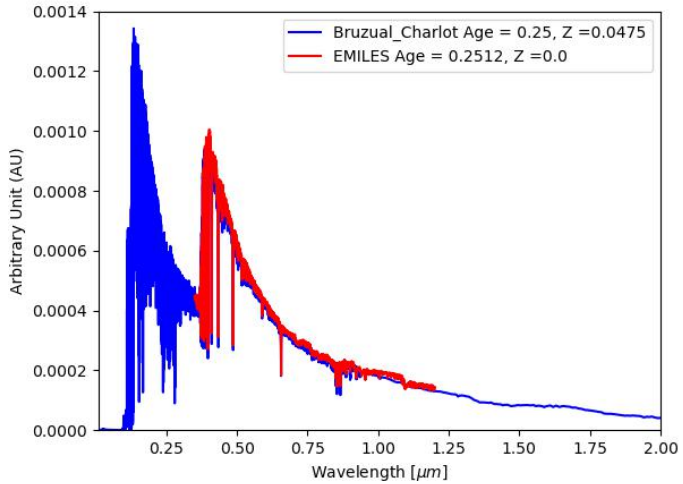
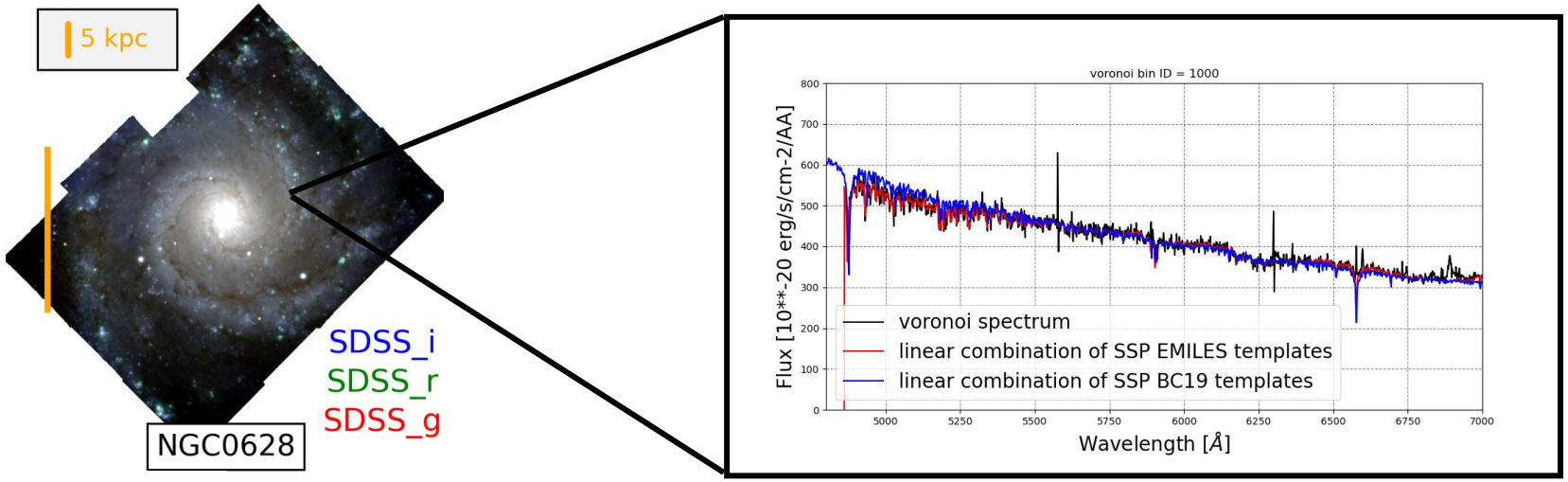


ISRF prediction



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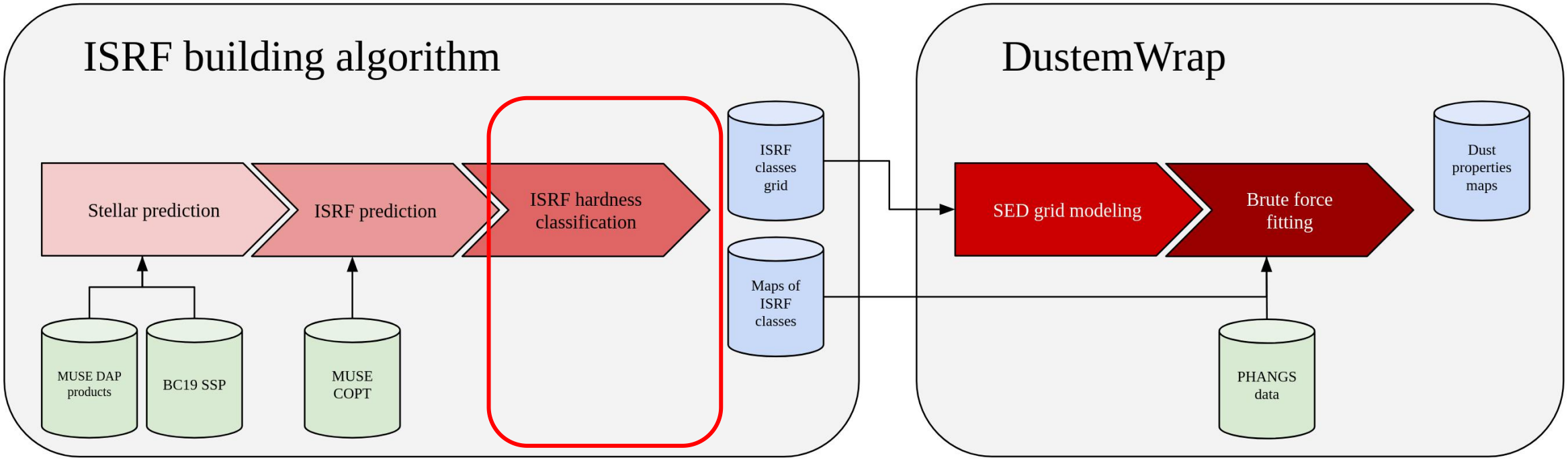
- Stellar prediction : $I_\nu^{*,unred} = \sum_i^N ssp_i w_i M_i^* / N_{pix}$

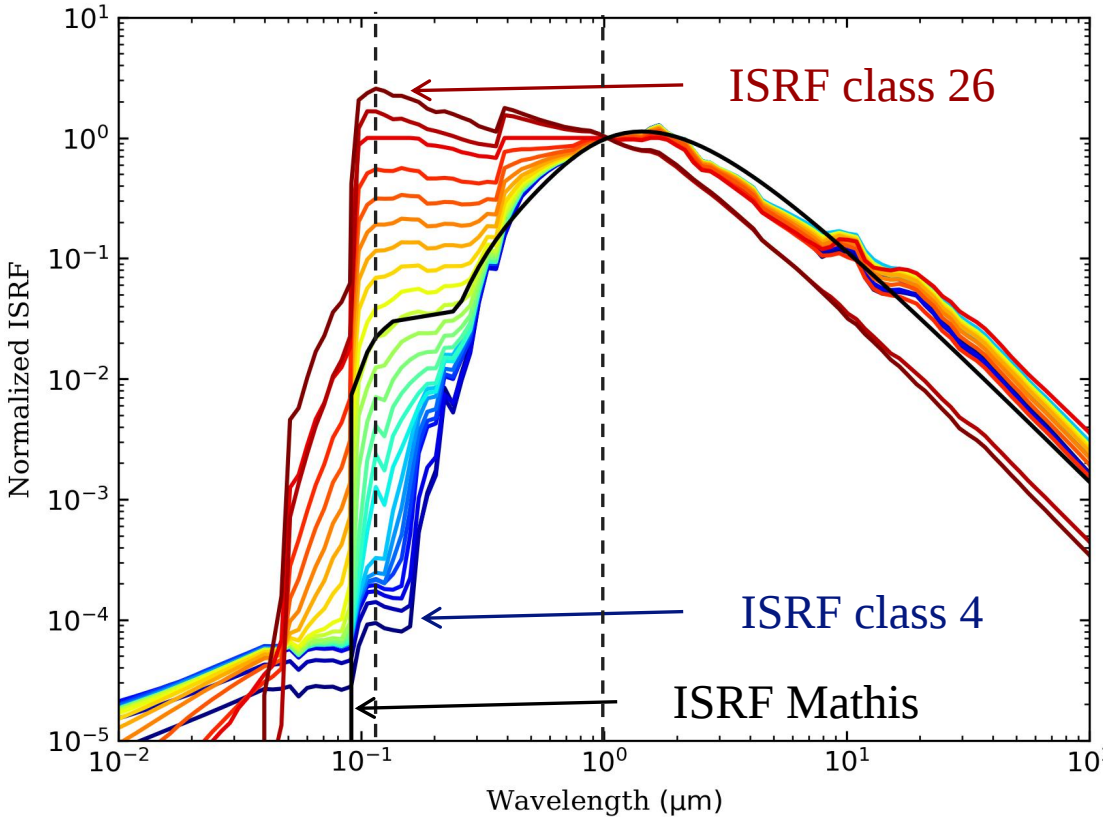
➡ **ISRF prediction :** $I_\nu^{ISRF,unred}$

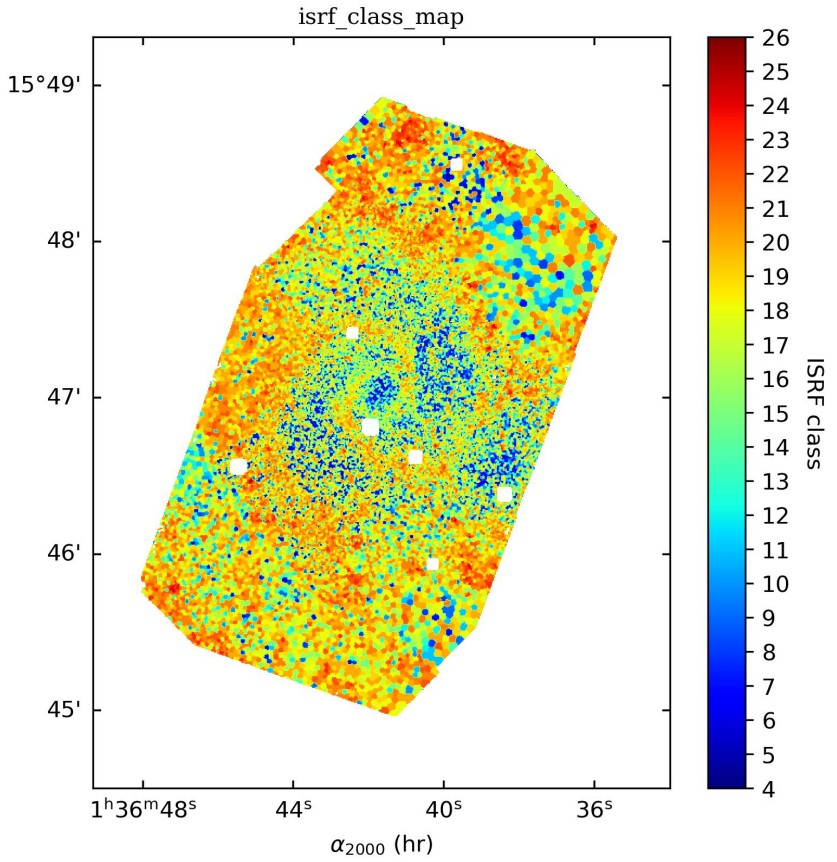
Method : ISRF hardness classification



- Each pixel of the galaxy has a unique ISRF
- Computing the dust SED grids with DustEMWrap for all the ISRFs is unfeasible
- To reduce the number of ISRFs, we proceed to a classification of ISRFs by their hardness

Classifying the ISRF hardness

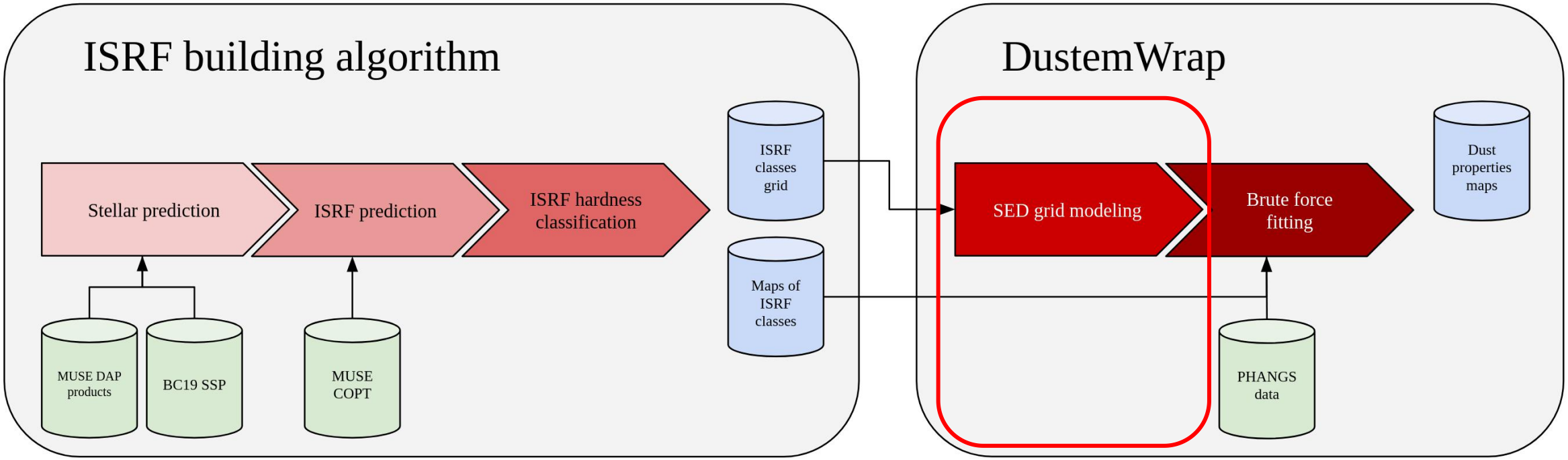




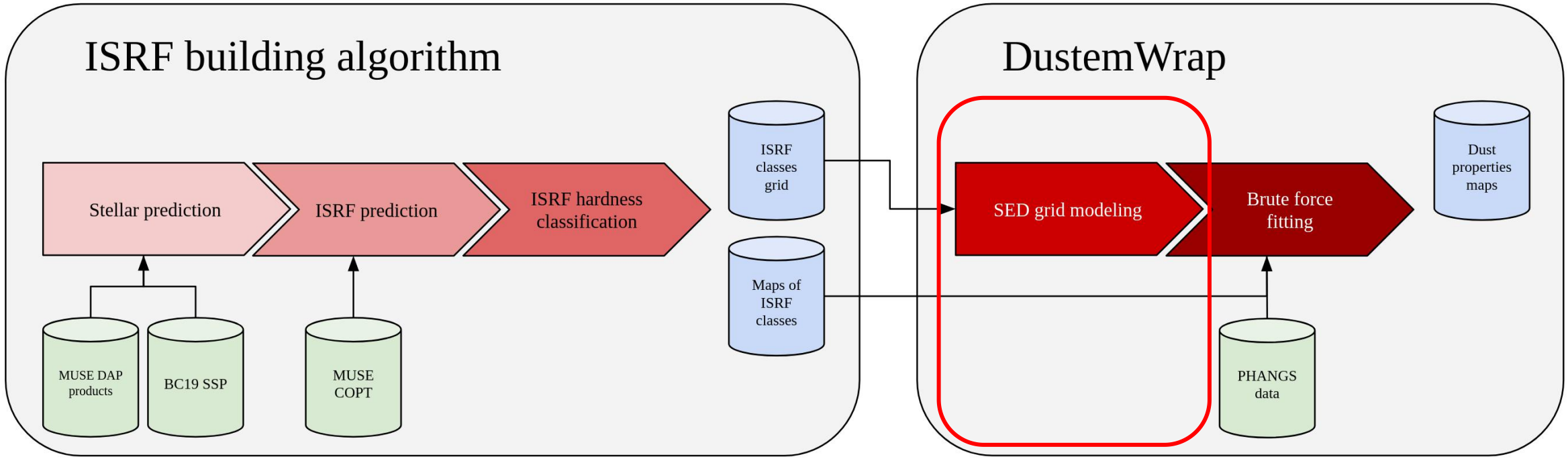
$$r_h = \frac{I_\nu^{ISRF}(\lambda_{UV})}{I_\nu^{ISRF}(1\mu m)}$$

- The hardness classification is determined by the slope between 0.15 um and 1 um
- We attribute an ISRF hardness class to each pixel
- At the end we have 22 representative ISRFs that capture the overall ISRF variations in NGC0628

Method : Generating grids of ISM dust SEDs



Method : Generating grids of ISM dust SEDs



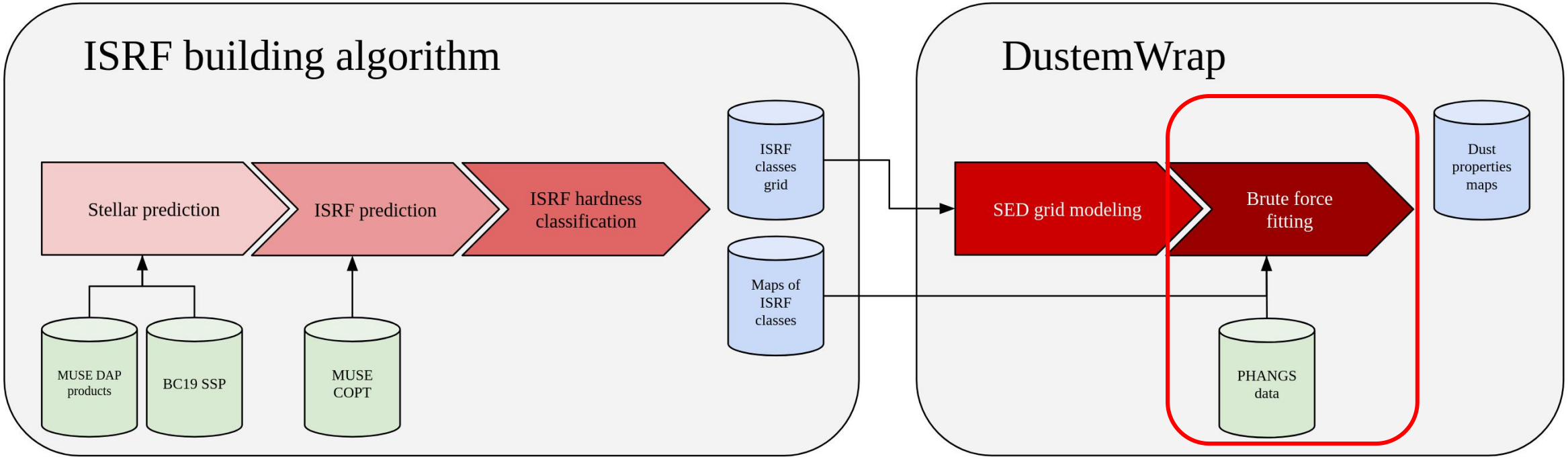
Model free parameters :

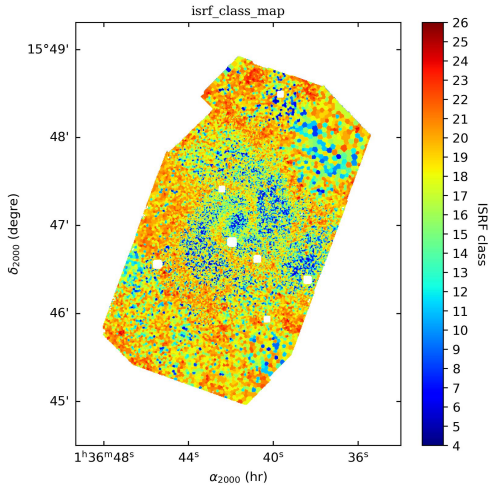
- **P1 : ISRF intensity G0**
- **P2 : PAH neutral, Y(PAH0)**
- **P3 : PAH ionized, Y(PAH1)**
- **P4 : VSG abundance, Y(VSG)**

Example SEDs grid computed for each ISRF class :

P1	P2	P3	P4	IASTROSAT2	IASTROSAT1	IASTROSAT3	...	ISPIRE3	TOTAL
float32	float32	float32	float32	float32	float32	float32	...	float32	float64
0.1	4.97e-05	4.97e-05	1.66e-05	1.0343524e-12	1.1005089e-12	1.4117349e-12	...	0.17253092	3.8791921138763428
0.1	4.97e-05	4.97e-05	2.4365469e-05	1.0343524e-12	1.1005089e-12	1.4117349e-12	...	0.17266288	3.8861093521118164
0.1	4.97e-05	4.97e-05	3.5763616e-05	1.0343525e-12	1.1005089e-12	1.4117349e-12	...	0.17285657	3.896261692047119
0.1	4.97e-05	4.97e-05	5.2493808e-05	1.0343525e-12	1.100509e-12	1.411735e-12	...	0.17314088	3.911163330078125
0.1	4.97e-05	4.97e-05	7.7050376e-05	1.0343525e-12	1.100509e-12	1.4117351e-12	...	0.17355819	3.9330365657806396
0.1	4.97e-05	4.97e-05	0.00011309448	1.0343526e-12	1.1005091e-12	1.4117352e-12	...	0.1741707	3.965141534805298
0.1	4.97e-05	4.97e-05	0.000166	1.0343527e-12	1.1005092e-12	1.4117353e-12	...	0.17506976	4.012265682220459
0.1	4.97e-05	4.97e-05	0.00024365468	1.0343529e-12	1.1005094e-12	1.4117356e-12	...	0.17638941	4.08143424987793
0.1	4.97e-05	4.97e-05	0.00035763616	1.0343532e-12	1.1005098e-12	1.411736e-12	...	0.17832637	4.18295955657959
0.1	4.97e-05	4.97e-05	0.0005249381	1.0343535e-12	1.1005102e-12	1.4117366e-12	...	0.18116944	4.3319783210754395
...	...	...	...	...	...	...	...	...	...

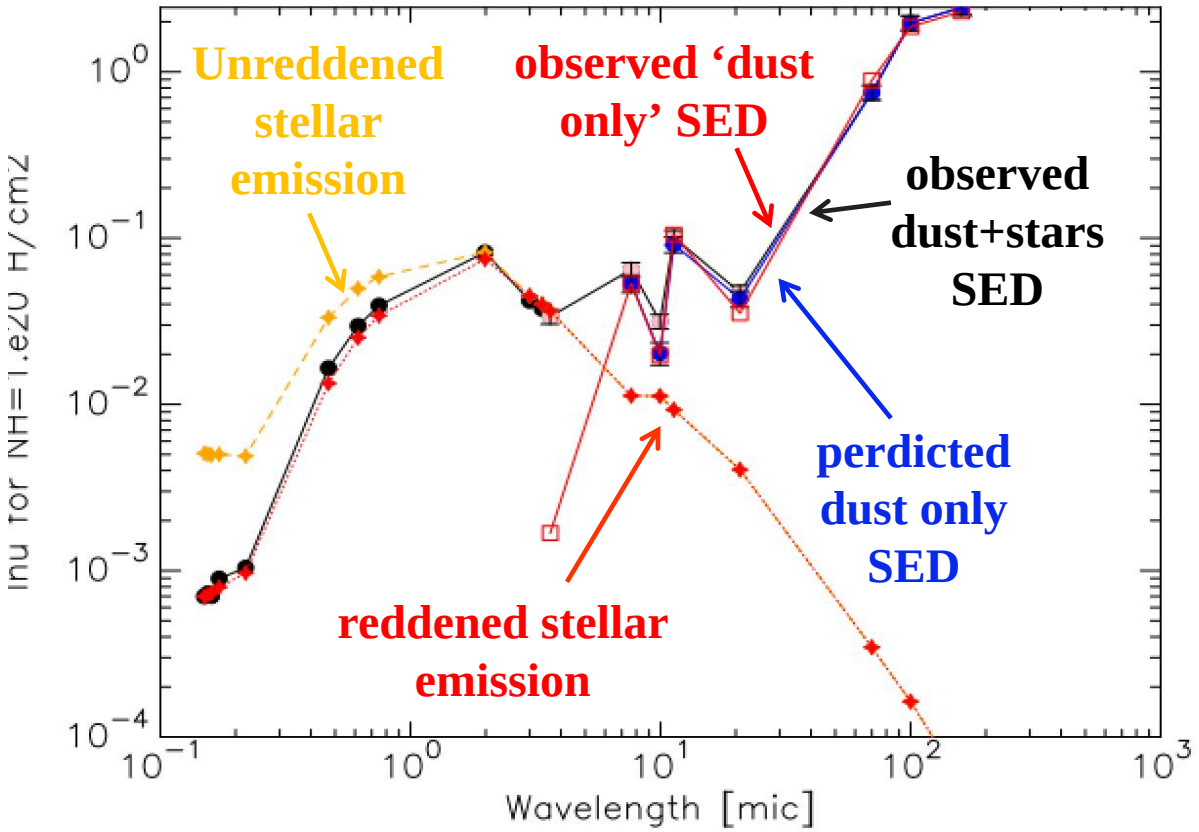
Method : ‘Brute force fitting’ the observed IR SEDs





Example SED fit

Example of SED fitted at Herschel 160 um resolution (~ 12”) :



We account for extinction using the Calzetti et al. (2000) prescription :

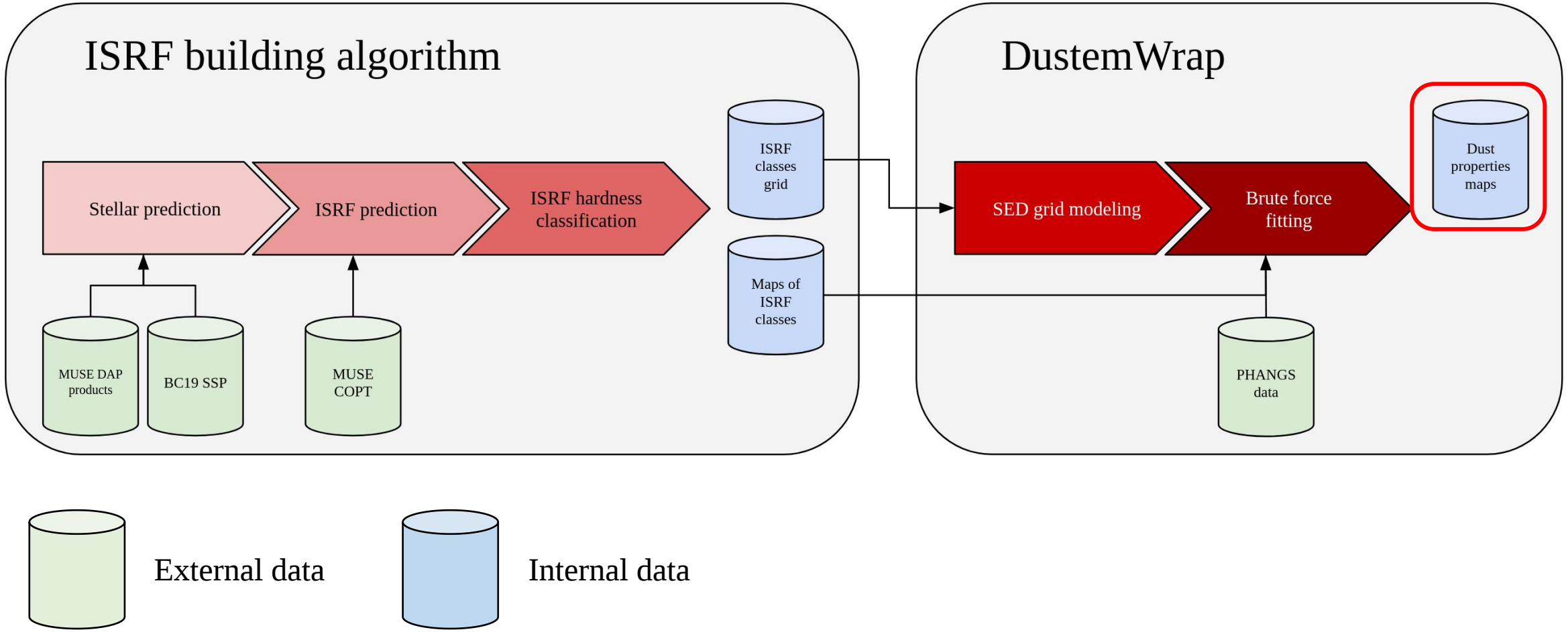
$$E_s(B-V) = \frac{1}{0.4k'(\lambda)} \log\left(\frac{\langle I^*_{\nu,pred}\rangle}{\langle I^*_{\nu,obs}\rangle}\right)$$

Reddened stellar emission :

$$I_\nu^{*,red} = I_\nu^{*,unred} * exp(-\tau(\lambda))$$

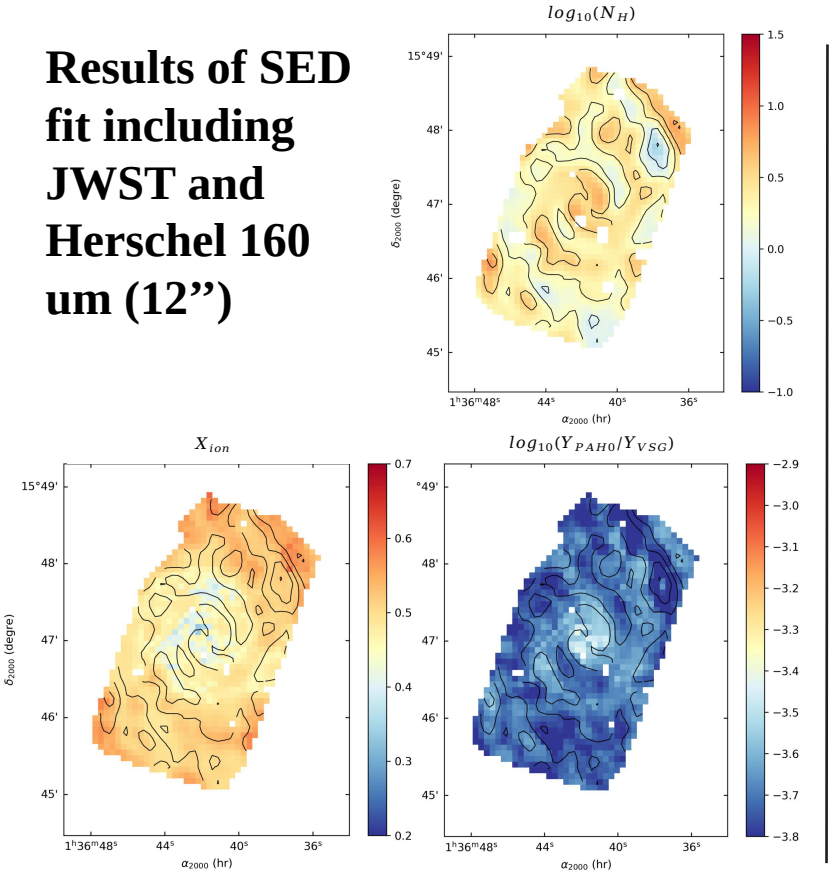
Calzetti, D., Armus, L., Bohlin, R. C., et al. 2000, ApJ, 533, 682

Results : Dust and ISRF parameter maps

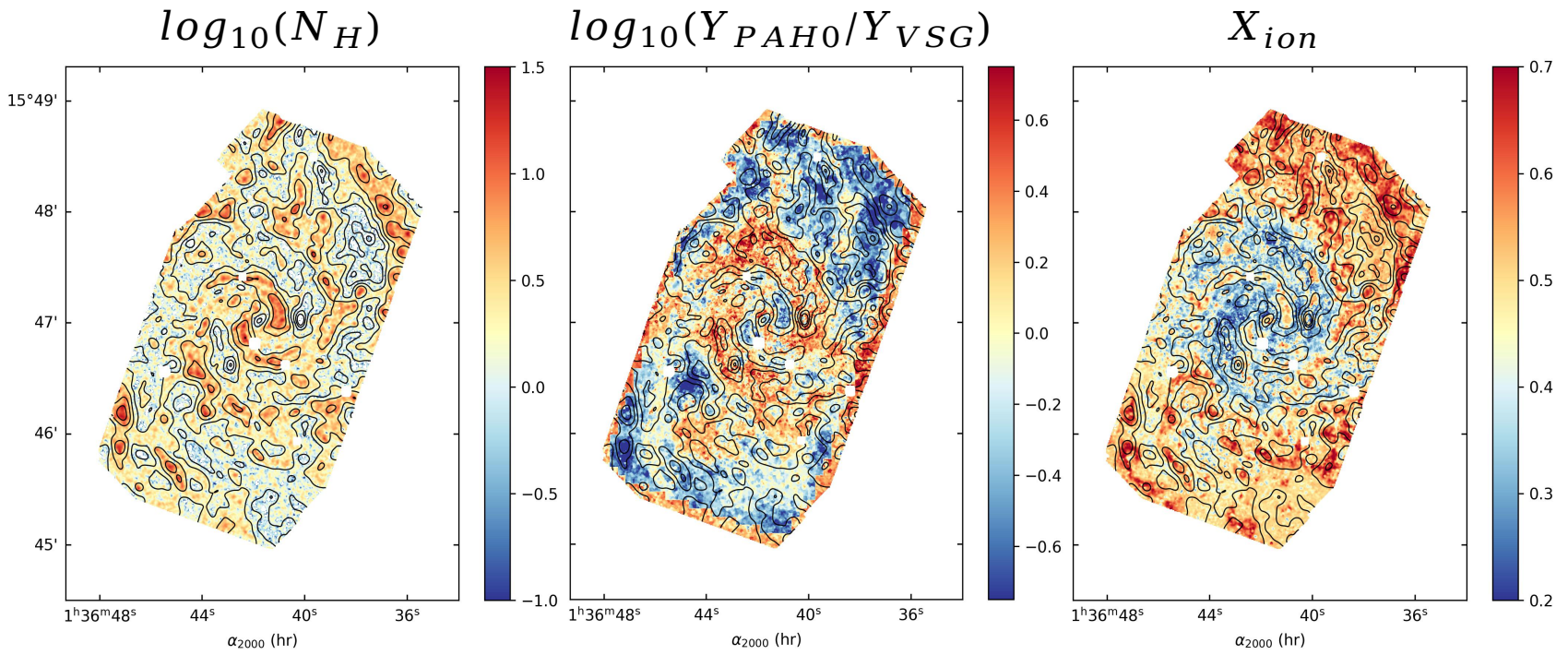


First results for NGC0628

Results of SED fit including JWST and Herschel 160 um (12”)



Results of SED fit using JWST NIRCAM+MIRI only (1”)

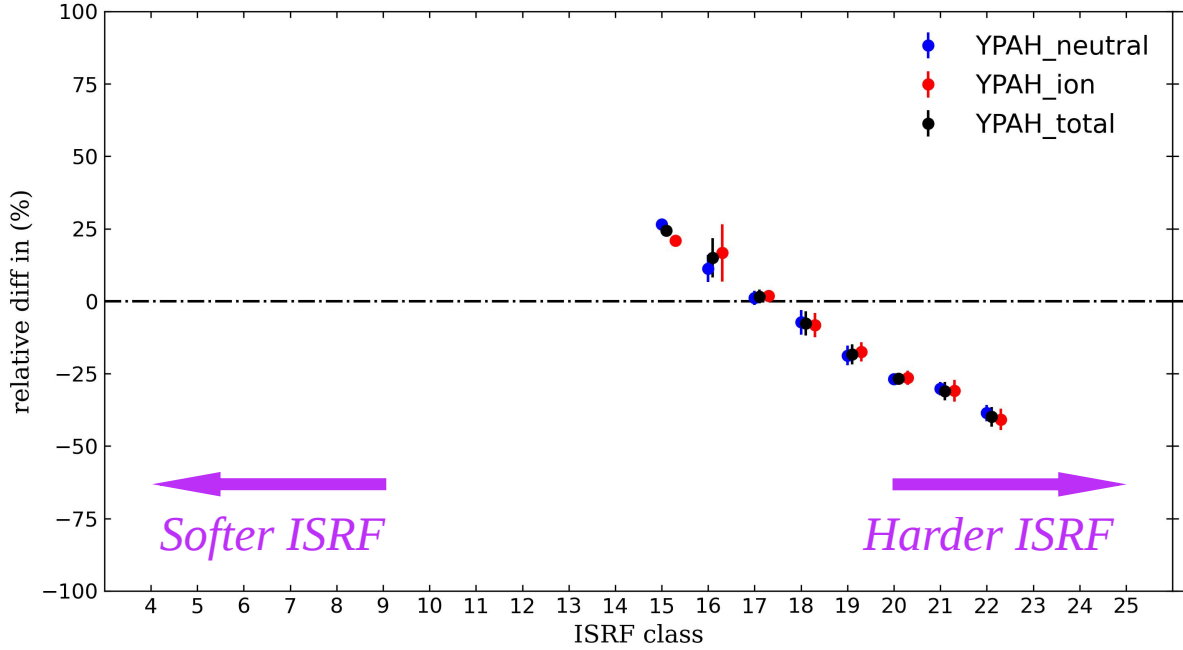


- Abundance of neutral PAHs tends to be lower in regions with high NH than regions with low NH
- Ionization fraction of PAH (Xion) tends to be higher in regions with high NH than regions with low NH

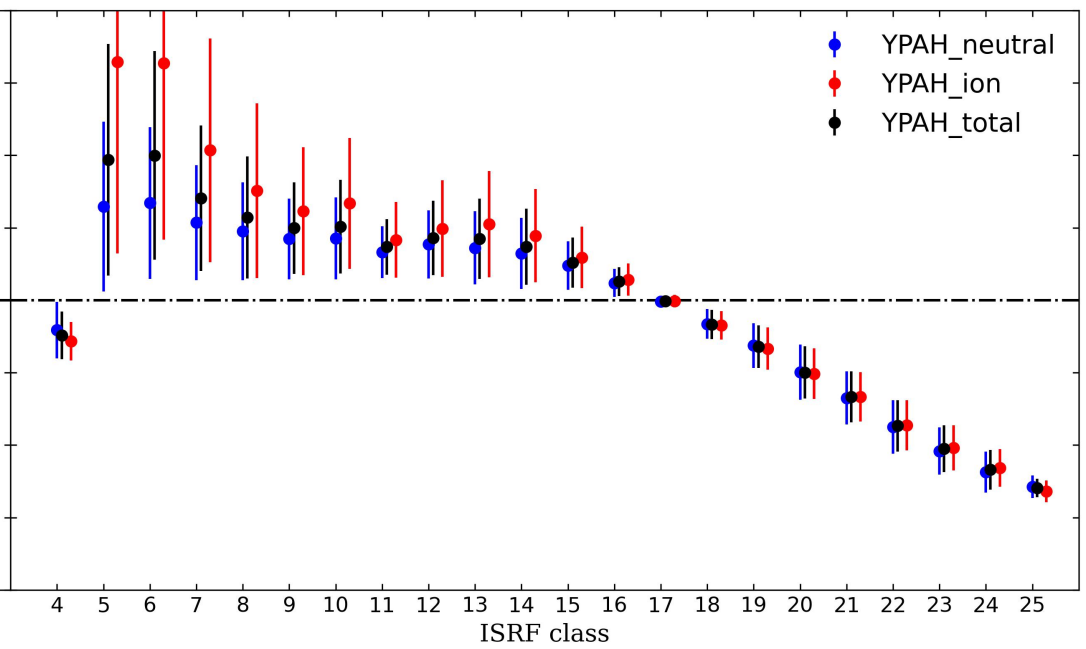
PAH abundances : true versus Mathis ISRF

% difference = (YG[true ISRF]-YG[Mathis ISRF])/YG[Mathis ISRF]

SED fit results JWST + Herschel 160 um (12”)



SED fit results JWST only (1”)



- Softer ISRF => older stars => assuming a Mathis ISRF tends to underestimate the PAH abundances (by up to 50%)
- Harder ISRF => younger stars => assuming a Mathis ISRF tends to overestimate the PAH abundances (by up to 75%)

Summary and Future Work

- We construct an empirical dust-heating ISRF at 100pc scales using the PHANGS MUSE data
- We estimate the PAH abundance using DustEM and the local, empirical ISRF for all pixels
- We find a significant, systematic differences between PAH abundances estimated with the true ISRF vs the Mathis ISRF
- Using the Mathis ISRF will
    1. overestimate the PAH abundance in regions with hard ISRF (by up to 75% in NGC0628)
    2. underestimate the PAH abundance in regions with soft ISRF (by up to 50% in NGC0628)

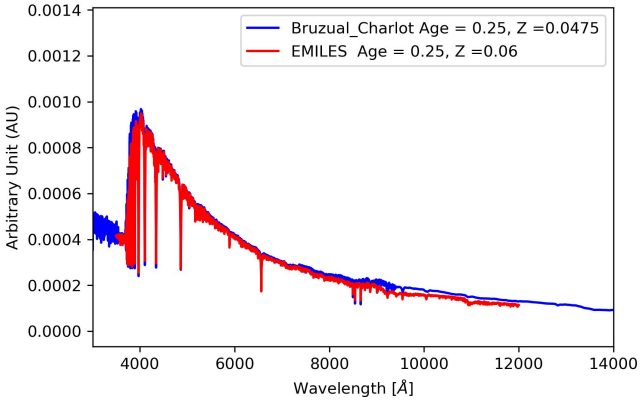
Next step: Expand application to remaining 10 PHANGS galaxies with suitable MUSE+JWST+Herschel data

Back up

Stellar emission prediction

The single stellar populations (SSPs) models :

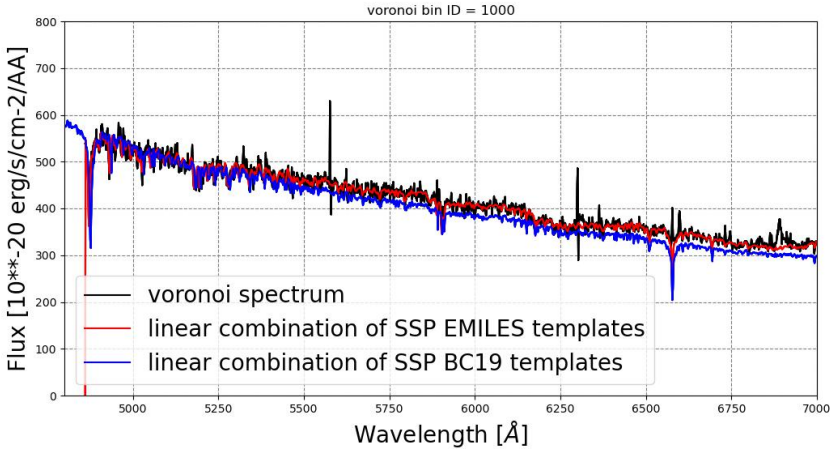
- **What used the MUSE team** : EMILES , Age = [0.03,13.5] Gyrs ; [Z/Zsol] = [-1.5 , 0.4] ; range = OPT
- **What we used :** BC19, Age = [0, 14] Gyrs ; [Z/Zsol] = [-2.2, 0.6] ; range = UV-OPT-IR



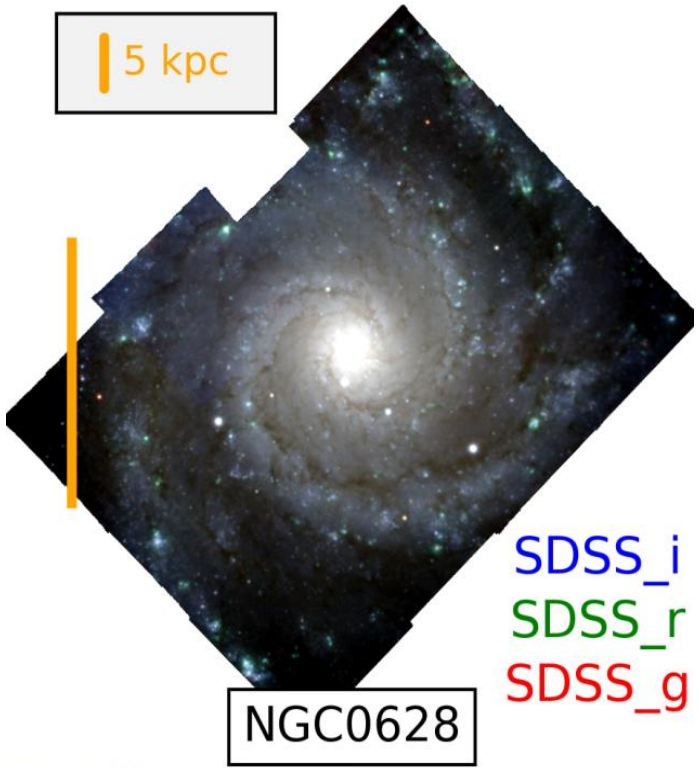
Stellar prediction : $I_{\nu}^{*,unred} = \sum_{i}^{N} ssp_i w_i M_i^* / N_{pix}$

w_i is the weight coefficient of the ssp_i at the given metallicities ($[Z/Zsol]_i$) and the age (Age_i)

ISRF prediction : $I_{\nu}^{ISRF,unred}$



ISRF prediction emission

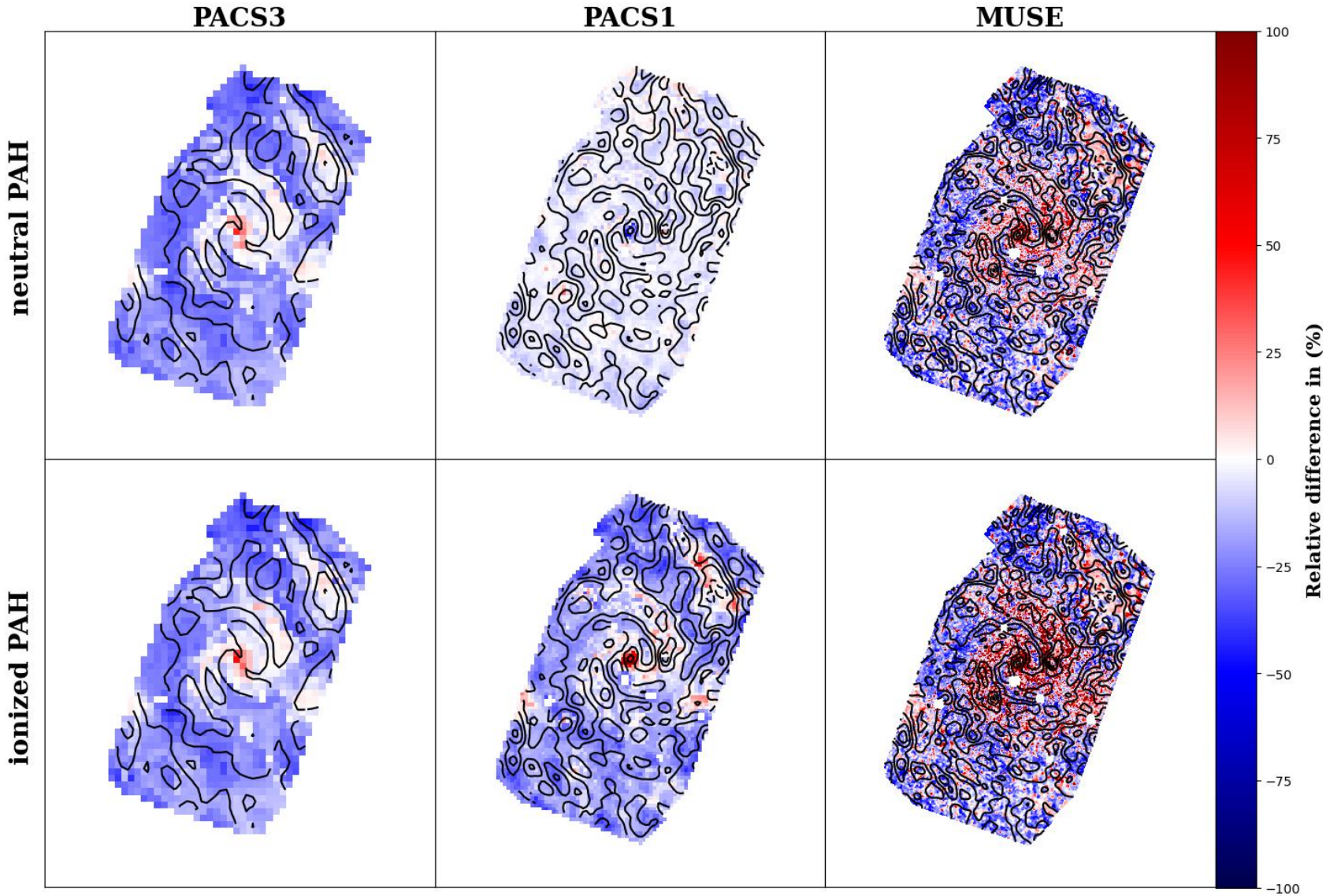


ISRF prediction : $I_{\nu}^{ISRF,unred} = I_{\nu}^{*,unred} \times \Omega$

- Ω is the solid angle. We used Ω=1 sr.
- smoothed at MUSE resolution
- normalized to the observed /MUSE filter image value

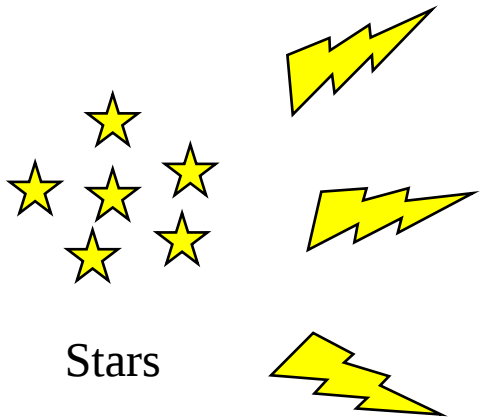
Relative differences in pah estimated abundance between our method vs mathis ISRF

diff= (YPAH[our method]-YPAH[with mathis])/YG[with mathis] :



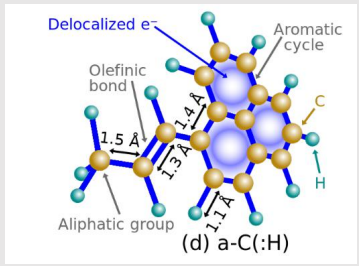
The relative difference is negative in arms and positive between arms

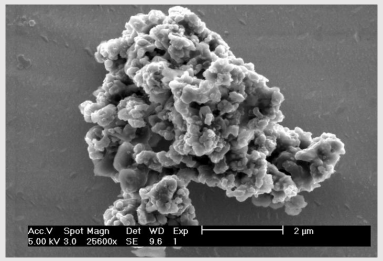
Introduction

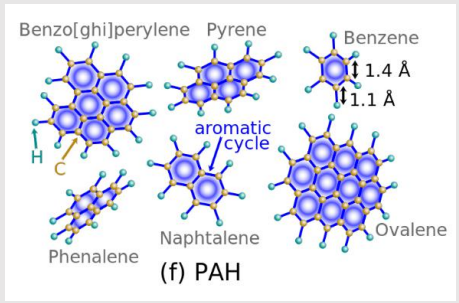


Stars

ISRF



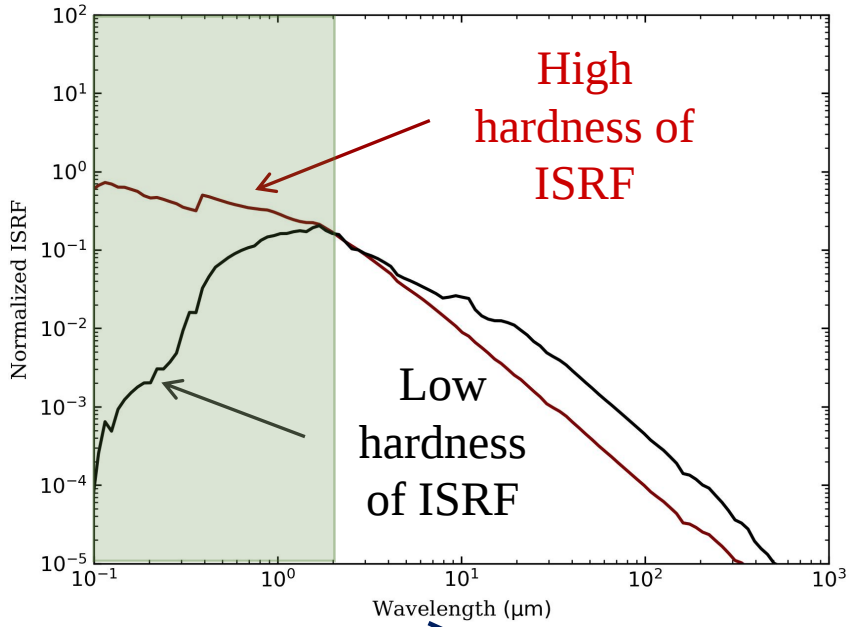


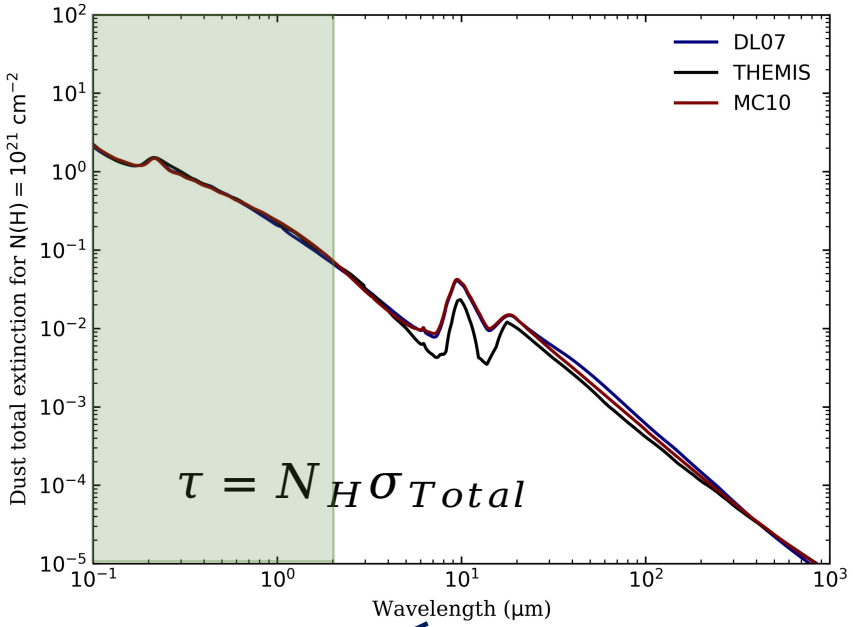


Interstellar dust

IR cooling emission

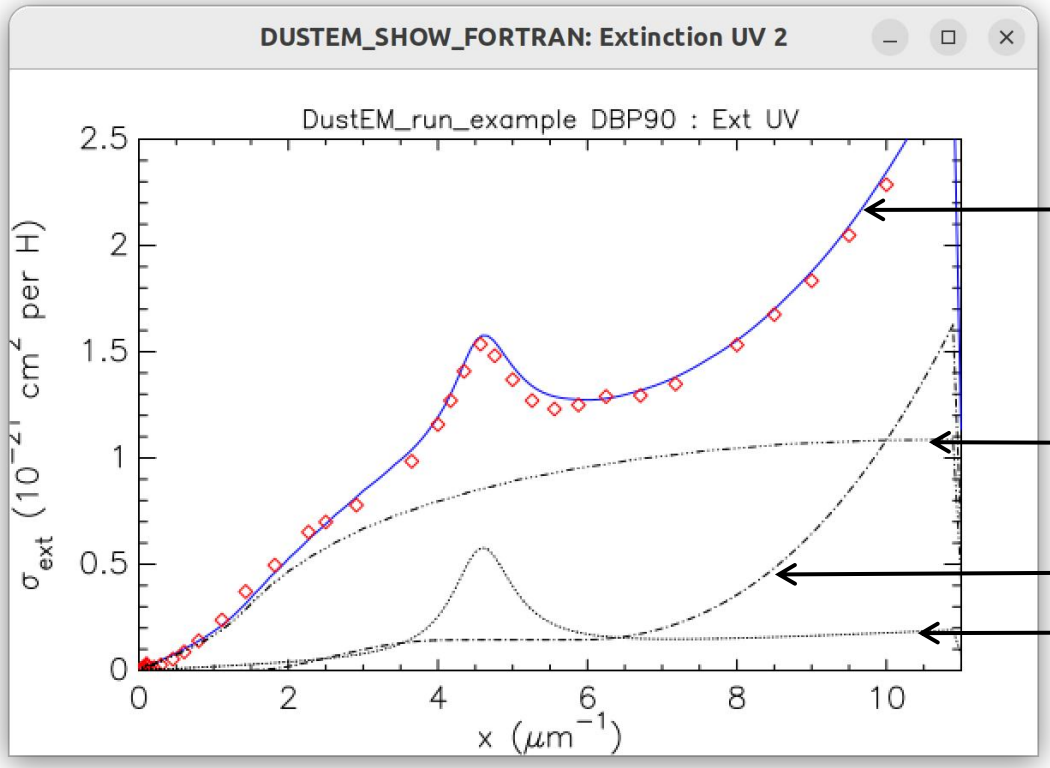
Why considering ISRF ?





$E_{abs} \propto G_0 * ISRF * \sigma_{Total}$ ⇒ If ISRF shape or intensity change, E_{em} change

Why considering ISRF shape ?



Total extinction curve

extinction from big grains

extinction from PAHs

extinction from VSGs

The ISRF shape is especially important for small grains

SED grid modeling

Parameters variation :

- P1 : ISRF intensity G0
- P2 and P3 : PAH abundance Y(PAH)
- P4 : VSG abundance Y(VSG)

SEDs grids computed with an ISRF class:

Parameters P1, P2 ... **SEDs**

P1	P2	P3	P4	IASTROSAT2	IASTROSAT1	IASTROSAT3	...	ISPIRE3	TOTAL
float32	float32	float32	float32	float32	float32	float32	...	float32	float64
0.1	4.97e-05	4.97e-05	1.66e-05	1.0343524e-12	1.1005089e-12	1.4117349e-12	...	0.17253092	3.8791921138763428
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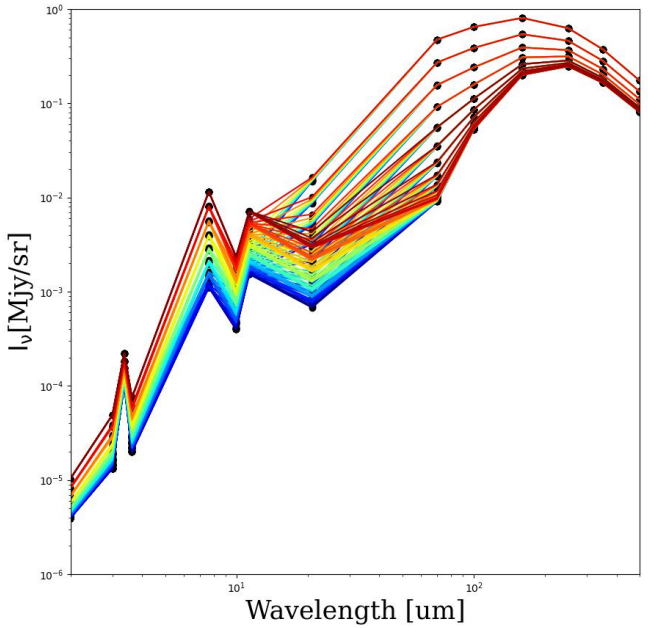
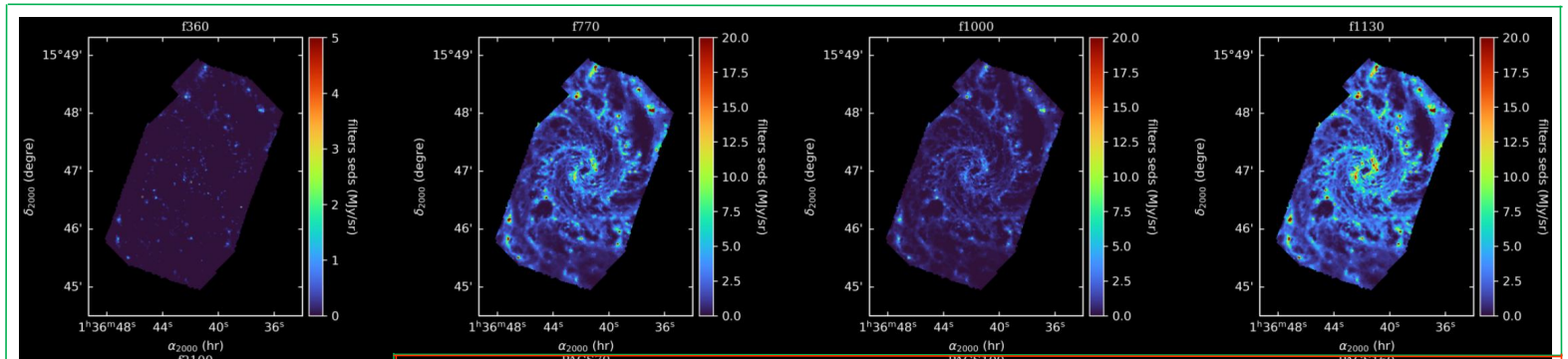
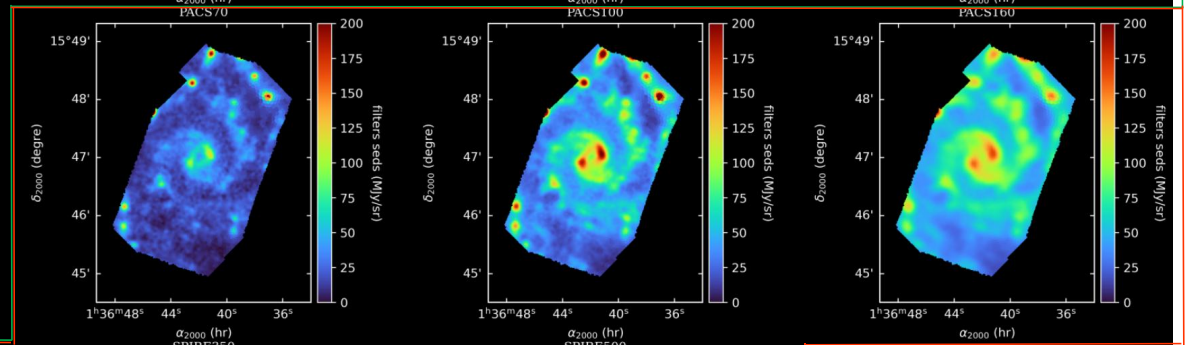
0.1	4.97e-05	4.97e-05	3.5763616e-05	1.0343525e-12	1.1005089e-12	1.4117349e-12	...	0.17285657	3.896261692047119
0.1	4.97e-05	4.97e-05	5.2493808e-05	1.0343525e-12	1.100509e-12	1.411735e-12	...	0.17314088	3.911163330078125
0.1	4.97e-05	4.97e-05	7.7050376e-05	1.0343525e-12	1.100509e-12	1.4117351e-12	...	0.17355819	3.9330365657806396
0.1	4.97e-05	4.97e-05	0.00011309448	1.0343526e-12	1.1005091e-12	1.4117352e-12	...	0.1741707	3.965141534805298
0.1	4.97e-05	4.97e-05	0.000166	1.0343527e-12	1.1005092e-12	1.4117353e-12	...	0.17506976	4.012265682220459
0.1	4.97e-05	4.97e-05	0.00024365468	1.0343529e-12	1.1005094e-12	1.4117356e-12	...	0.17638941	4.08143424987793
0.1	4.97e-05	4.97e-05	0.00035763616	1.0343532e-12	1.1005098e-12	1.411736e-12	...	0.17832637	4.18295955657959
0.1	4.97e-05	4.97e-05	0.0005249381	1.0343535e-12	1.1005102e-12	1.4117366e-12	...	0.18116944	4.3319783210754395
...	...	...	...	...	...	...	...	...	...

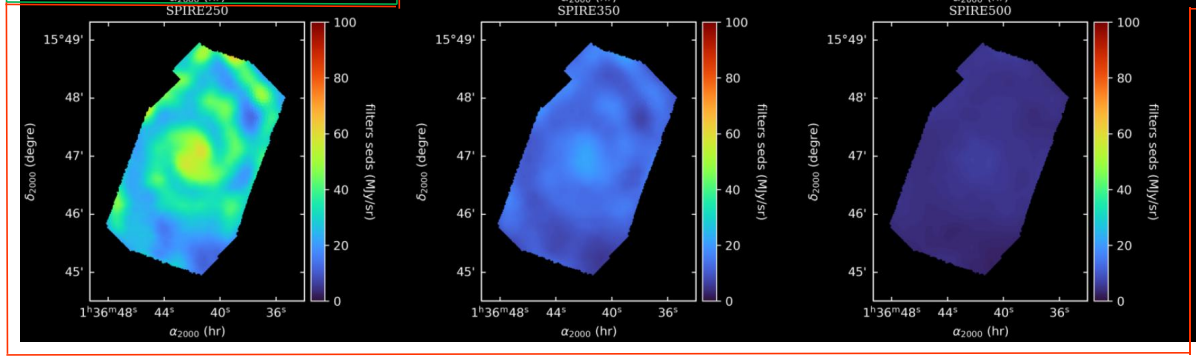


NGC0628 native resolution SEDs (the PHANGS data)

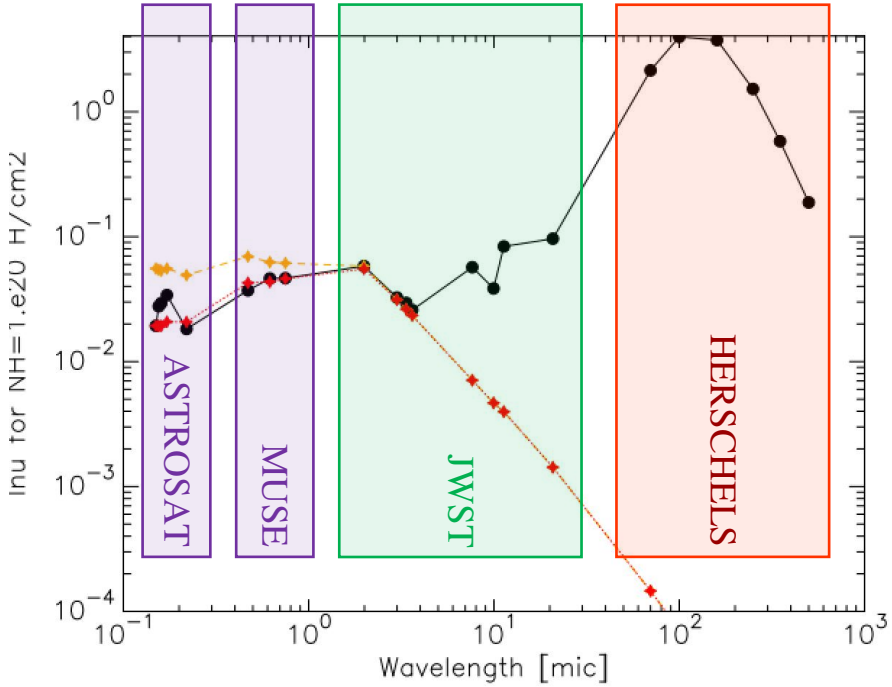
JWST

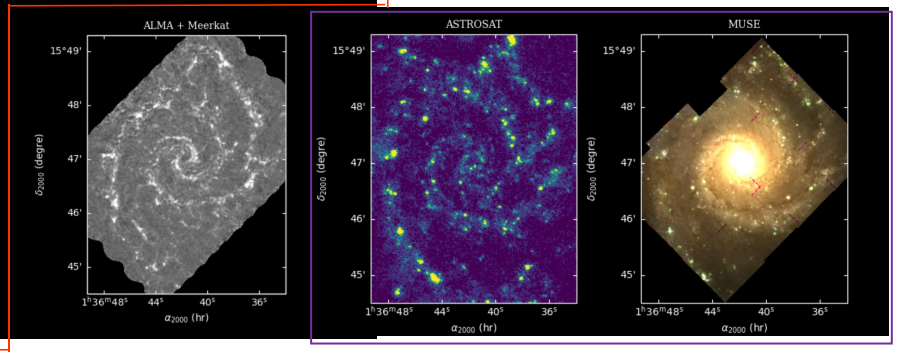






HERSCHEL





ASTROSAT & MUSE

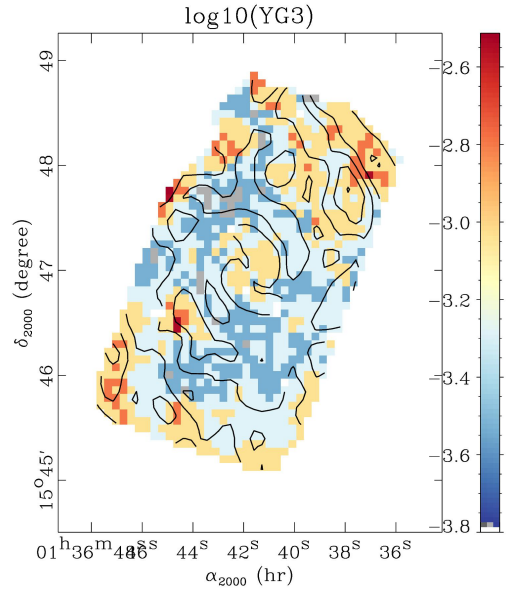
However, how we will fit SEDs at better resolution ?

$$I_\nu(21\ \mu m)\ \alpha\ Y_{VSG} \times \overline{ISRF} \times G_0$$

We used the parameters of abundance of VSGs measured at the resolution of PACS3 (160 µm) to predicted the parameters of Ypah at better resolution

Two assumptions :

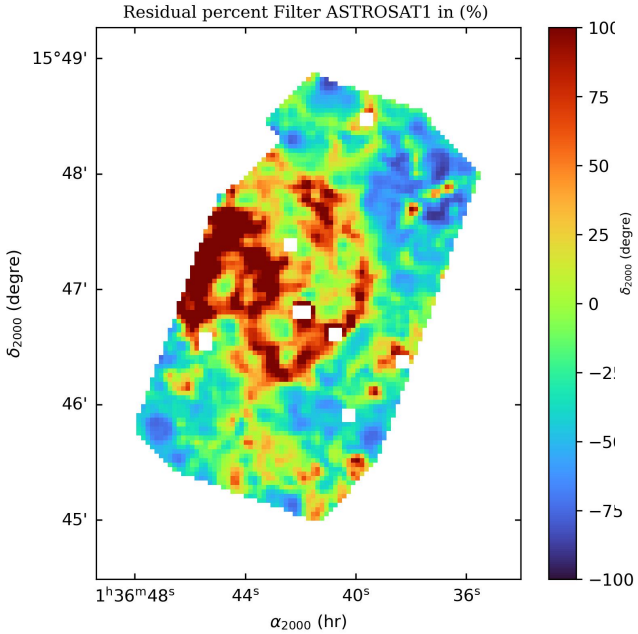
- The dust grain distribution see the same intensity of ISRF beam
- The dust see the same hardness ISRF beam
- The abundance of VSGs remain constant at better resolution



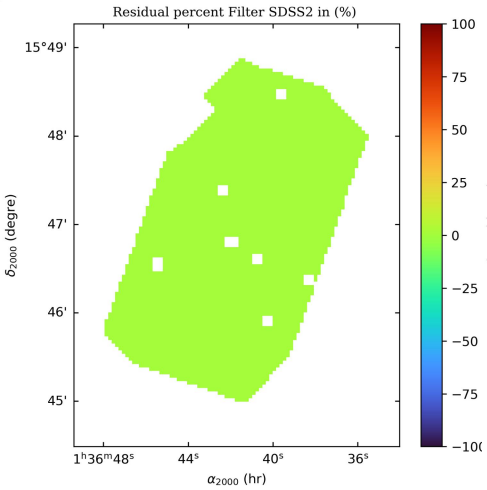
Residuals

diff= (SEDs[predicted]-SEDs[obs])/SEDs[obs]

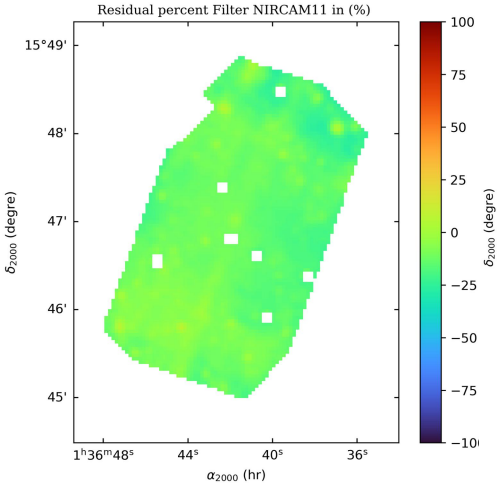
Astrosat



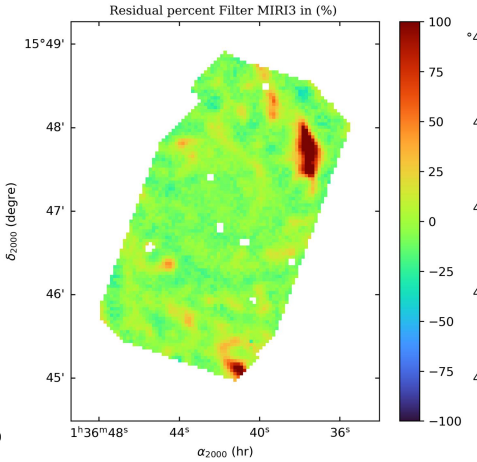
Muse copt



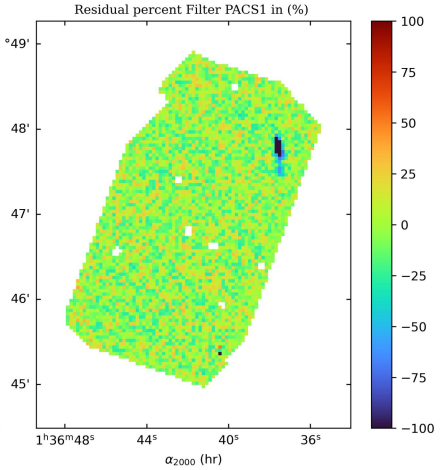
Nircam



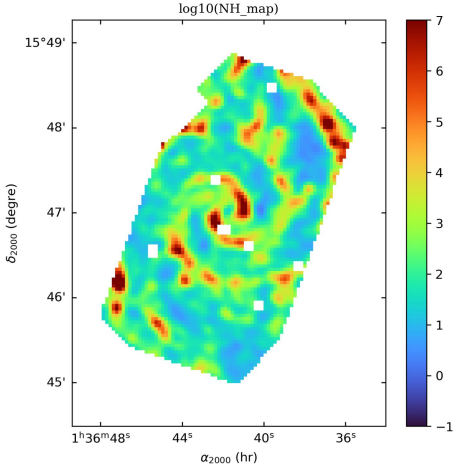
Miri



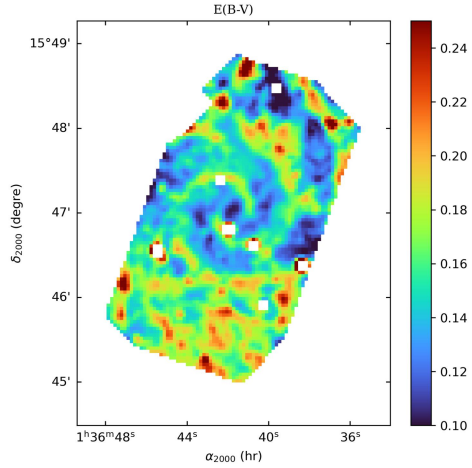
Herschel 70 um



NHmap



E(B-V)



- There is an overestimation between the intensity predected SED and the intensity of obseved SED
- The extinction in ASTROSAT data is underestimated
- But not correlated with E(B-V) and NH ...