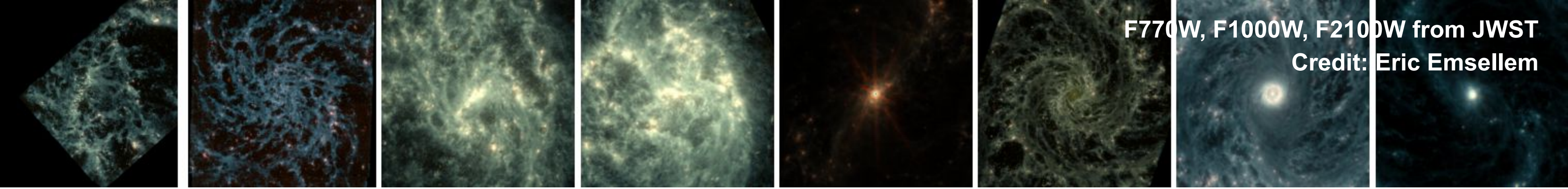

New constraints on the physics of the embedded feedback phase with JWST

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Institut für Theoretische Astrophysik

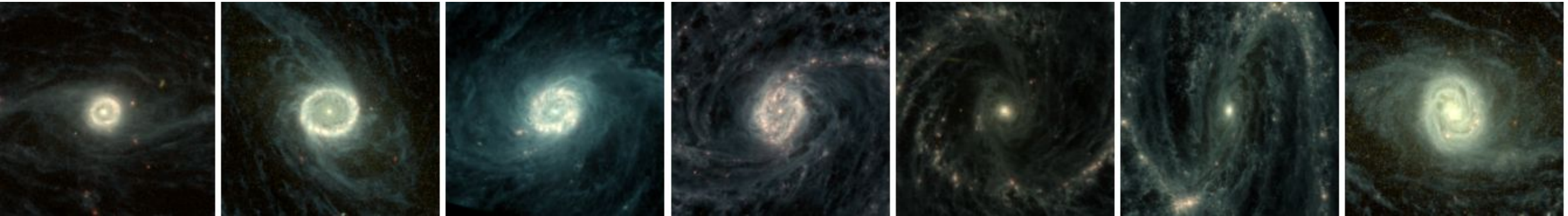
Emmy Noether-Programm
DFG Deutsche Forschungsgemeinschaft

Star Formation, Stellar Feedback, and the Ecology of Galaxies

Celebrating John Bally's lifetime in Astronomy - 28.05.25

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

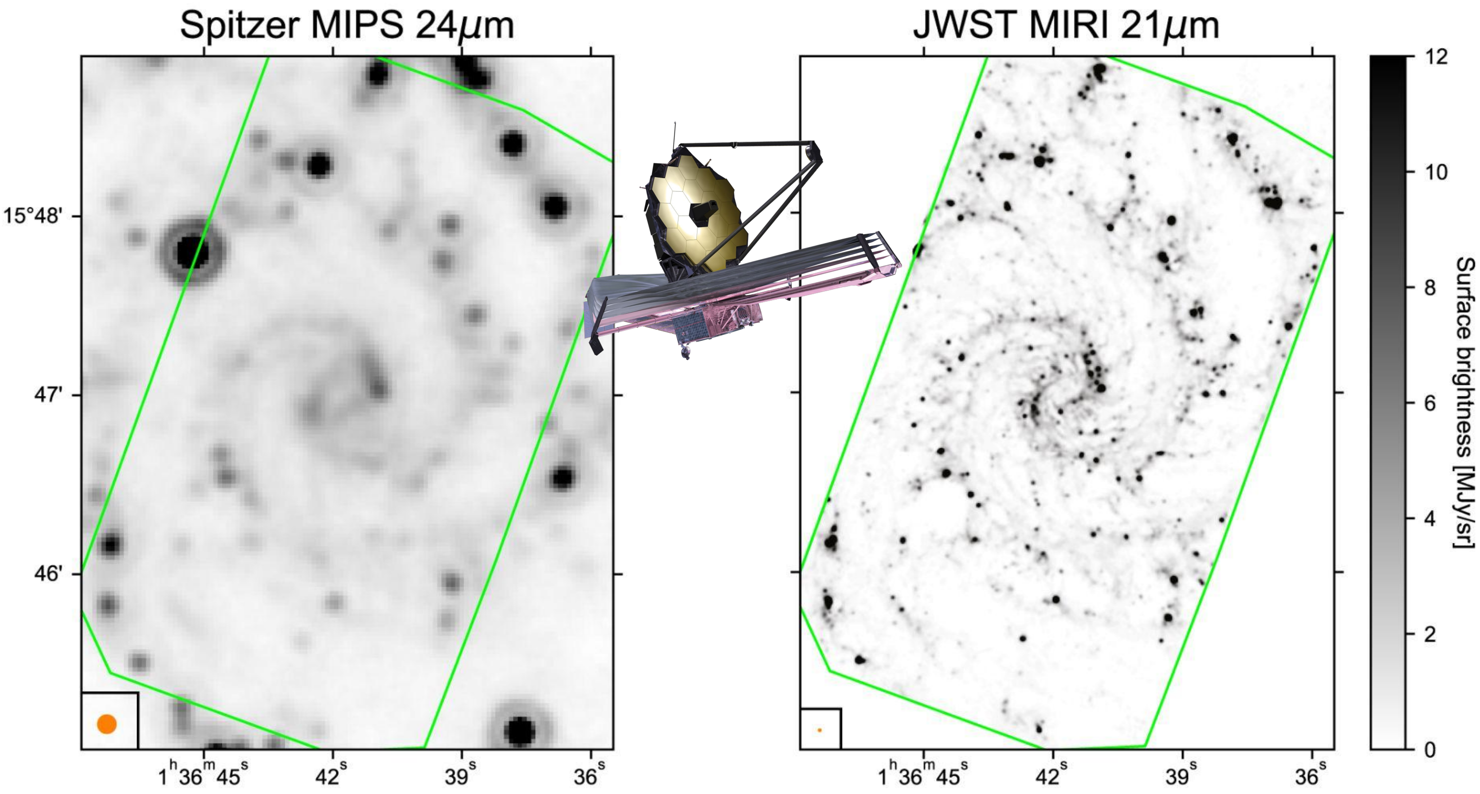
ZENTRUM FÜR ASTRONOMIE



Phangs

I - Context : star formation and its dust-embedded phase

The JWST reveals fainter and more compact sites of star formation

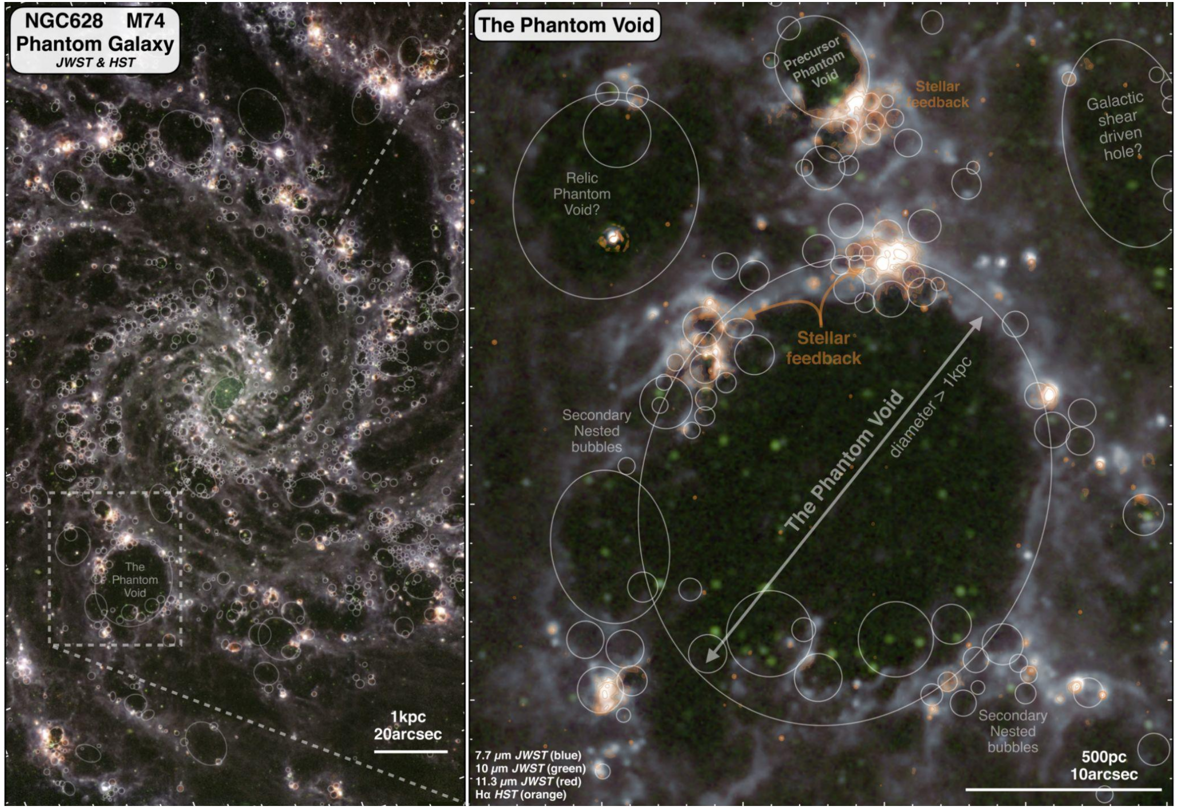


- sensitivity
- spectral resolution
- spatial resolution

Galaxie NGC 628, Kim et al. 2023

I - Context : star formation and its dust-embedded phase

How to disentangle the signatures of stellar feedback mechanisms ?



Barnes et al. 2023

Star formation cycle :

1. <u>how</u> it started ?
2. <u>how</u> efficient ?
3. <u>which</u> feedback processes ?

⇒ evolution over cosmic times

Multiscale, multiwavelength, and evolving processes

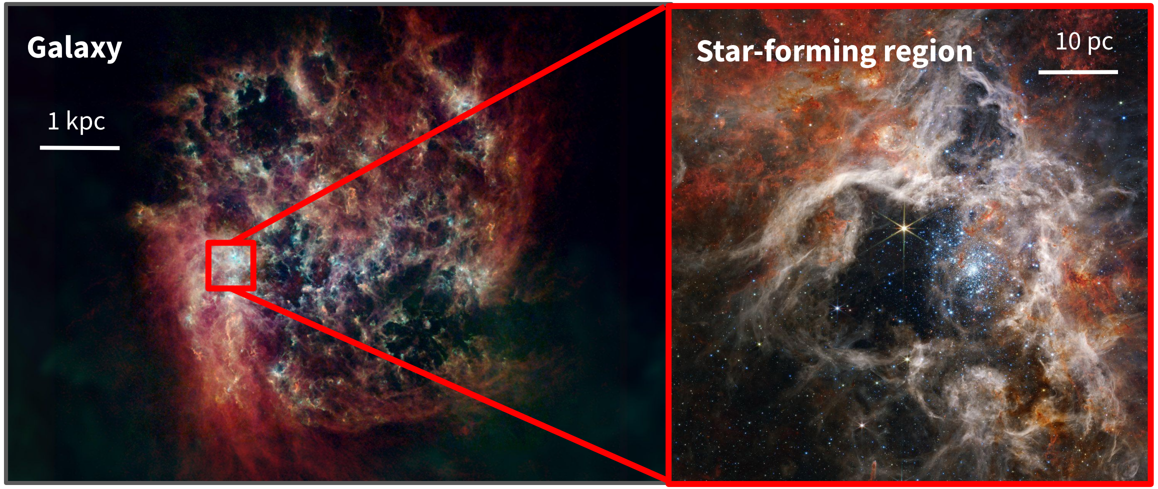
In this talk:

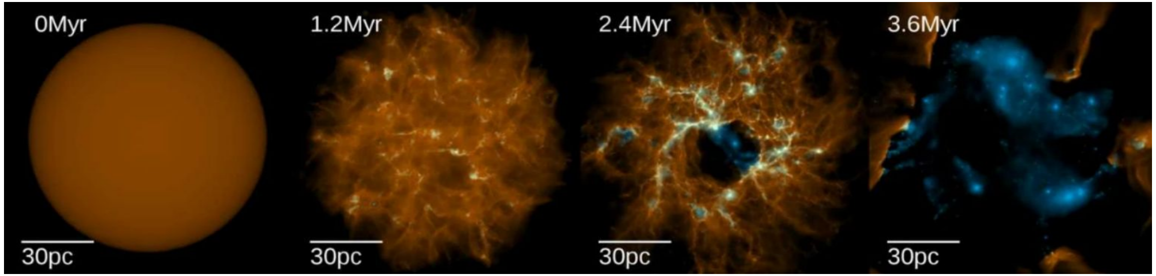
- *50 pc → 10 kpc*
- *mm → optical tracers*
- *GMC formation → destruction*

(10-30 Myr, Chevance et al. 2020, Kim et. al. 2022)

I - Context : star formation and its dust-embedded phase

Constraining the evolutionary timeline of star-forming regions





Large Magellanic Cloud, ESA/NASA/JPL-Caltech/CSIRO/C. Clark (STScI), Fahrion et al. 2024, Grudić et al. 2018

Evolutionary timelines depend on :

→ **feedback mechanisms**
e.g., Smith+21, Semenov+21

→**GMC properties (incl. chemistry)**
e.g., Fukushima+20, Yoo+20

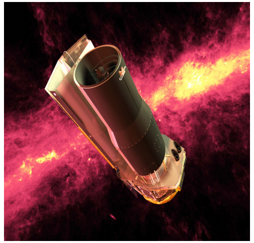
→ **galactic properties**
e.g., Chevance+20, Kim+22

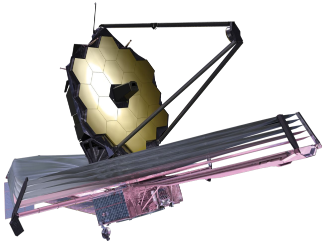
… varies **within galaxies from region to region**
e.g., Chevance+22, Romanelli+25

See Xinyue Liang's poster on local variations in the LMC !

I - Context : star formation and its dust-embedded phase

Constraining the evolutionary timeline of star-forming regions

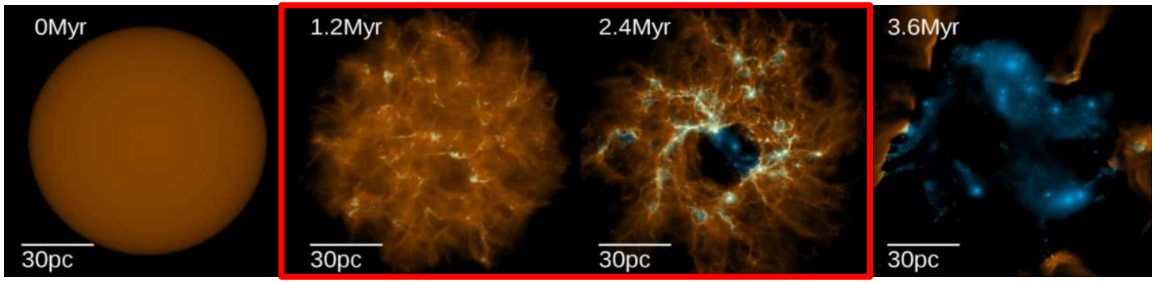




- What are the **timescales of the mid-infrared emitting phase** ?
- Which **physical processes** regulate the transition from dust-embedded to optically thin star-formation ?
- Is this transition universal, or does it vary with environment (**large scale galactic properties** vs. **local physical conditions)** ?

"embedded" star formation phase emitting in mid-IR

See also Angela Adamo's talk



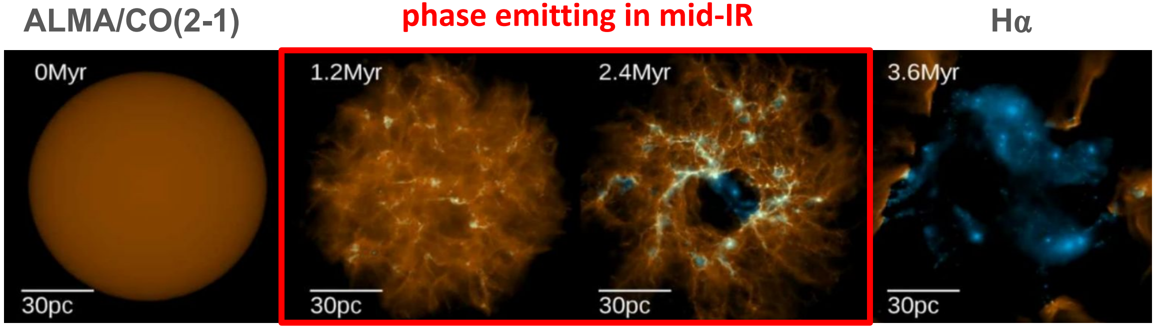
Large Magellanic Cloud, ESA/NASA/JPL-Caltech/CSIRO/C. Clark (STScI), Fahrion et al. 2024, Grudić et al. 2018

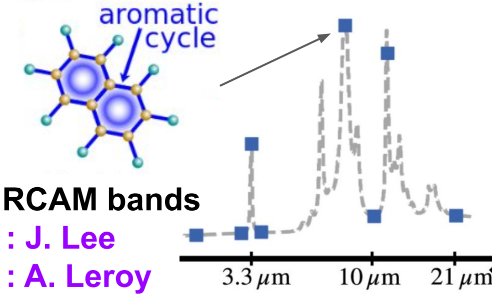
II - Data : PHANGS, a diversity of nearby star-forming environments

PHANGS-ALMA : Leroy et al. (2021)
PHANGS-Hα: Razza et al. subm
PHANGS-JWST: Lee et al. (2023), Williams et al. (2024), Chown et al. (2025)

PHANGS-JWST 74 galaxies !
Ryan Chown's talk on Tuesday

early "embedded" star formation phase emitting in mid-IR





8 MIRI and NIRCAM bands
GO #2107, PI : J. Lee
GO #3707, PI : A. Leroy

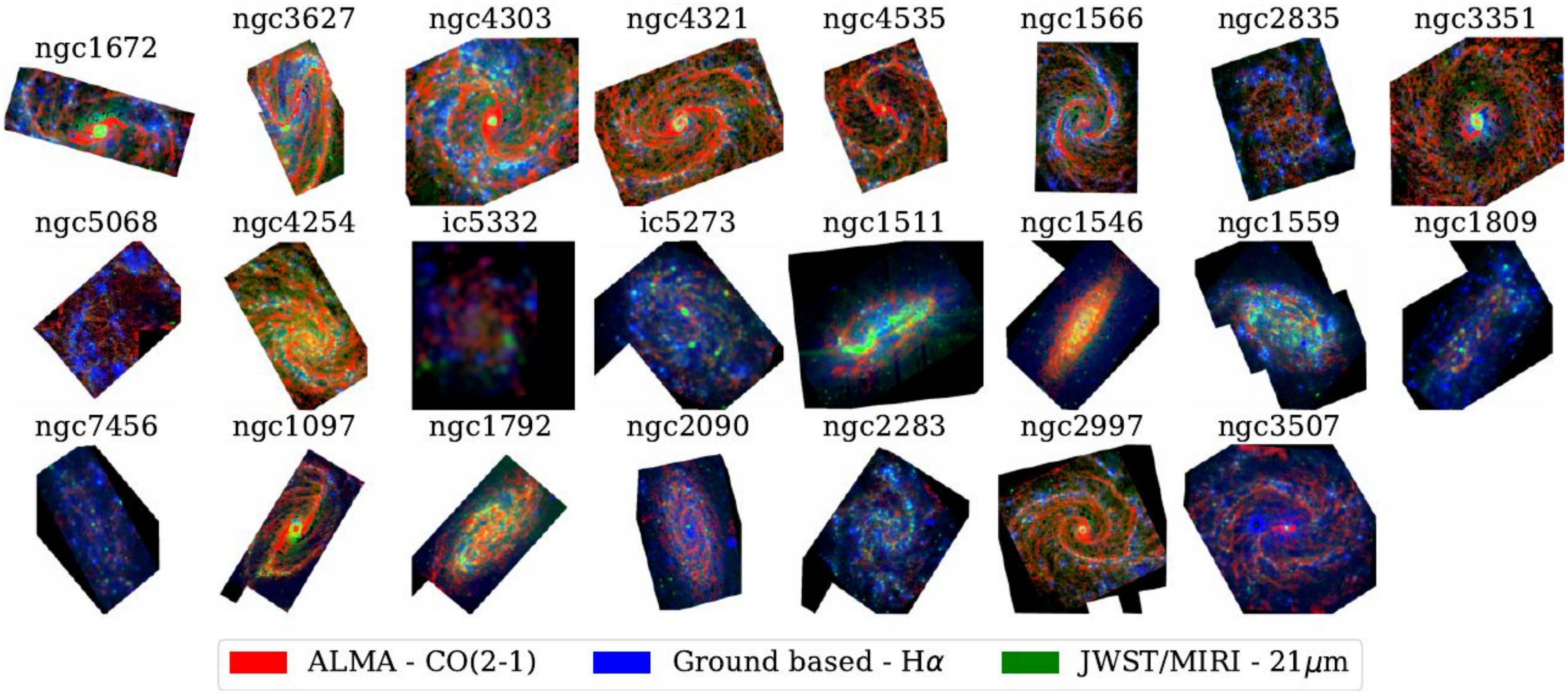
MIRI/21μm trace the **dust continuum**
⇒ best proxy for embedded SFR in star-forming regions
Belfiore et al. 2023

II - Data : PHANGS, a diversity of nearby star-forming environments

Sub-sample selection :

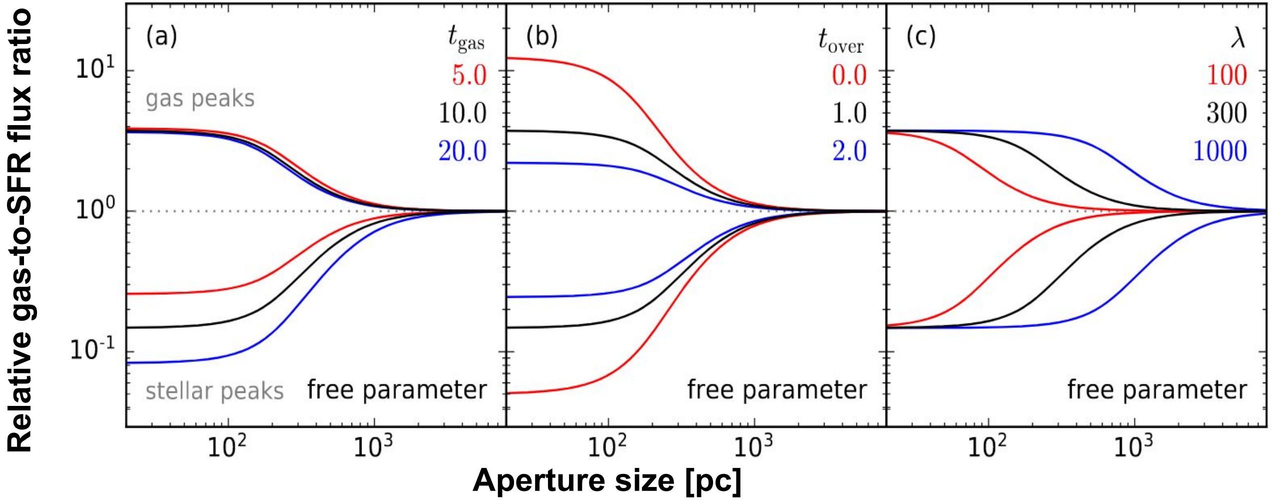
- **observed in CO, 21µm, and Hα**
- **sufficient resolution (< 180pc) to resolve decorrelation between 21µm and CO**

⇒ 37 galaxies with a wide range of physical properties and morphologies



III - Method : interpreting gas and stars de-corellations with the “tuning-fork”

Kruijssen & Longmore 2014, Kruijssen et al. 2018



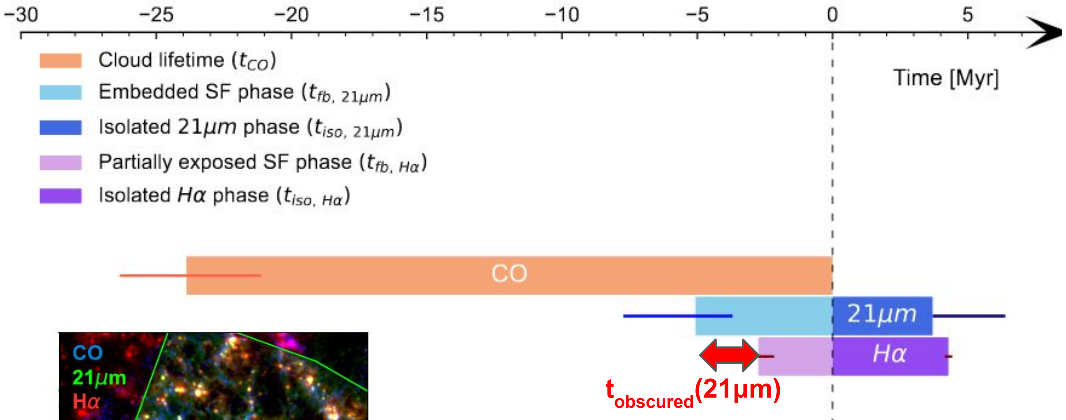
3 independent parameters:

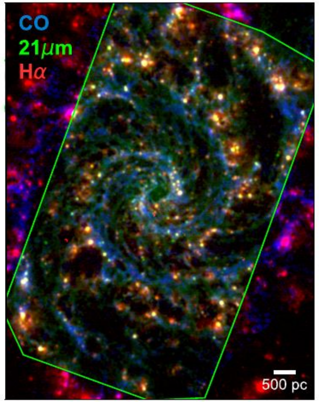
- t_{gas} : the timescale of emission of the gas tracer
- t_{over}: the timescale of stellar feedback
- λ: the spatial scale at which the SFR and gas tracers decorrelate

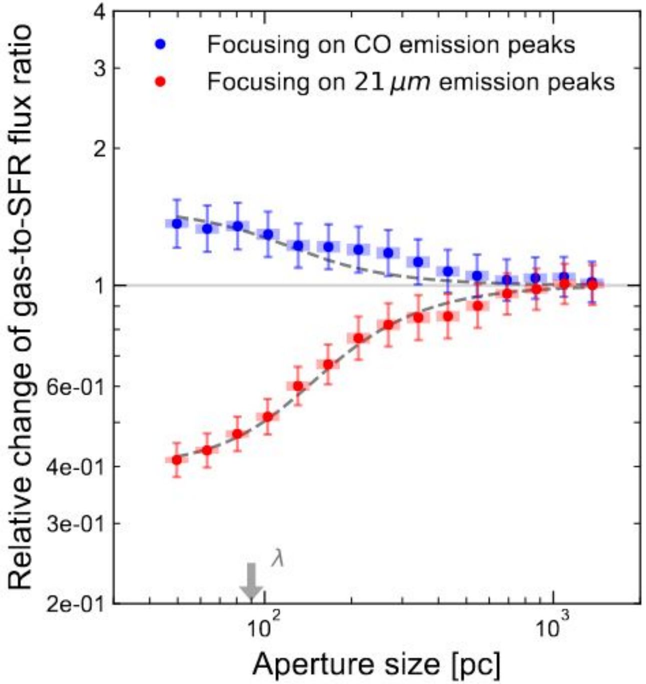
Applied to local observations and simulations !
⇒ Mélanie Chevance’s talk on Tuesday

III - Method : measuring the duration of the dust-obscured phase of SF

Kim et al. 2021, Kim et al. 2023







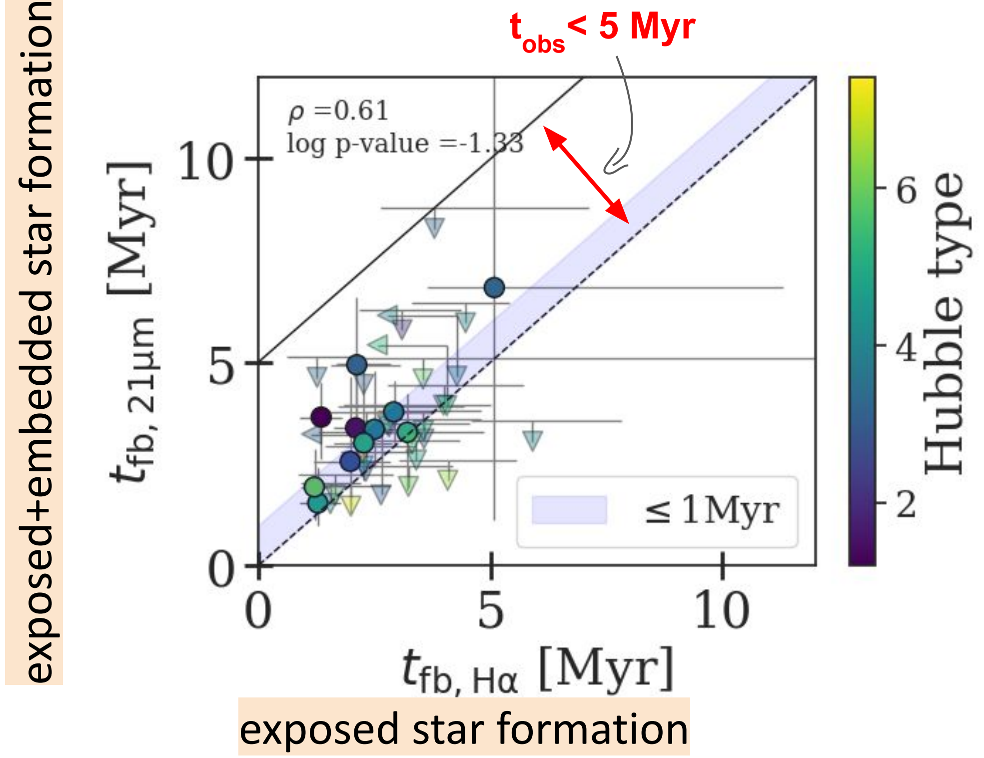
$t_{obscured}$(21µm)= $\mathbf{2.3^{+2.7}_{-1.4}}$ **Myr**

Is the dust-obscured phase of SF this short in all galaxies ? dependencies ?

III - Results : measuring the timescales associated with the dust-embedded SF

1. Is the dust-obscured phase of star-formation short in all galaxies ?

Ramambason et al. in prep



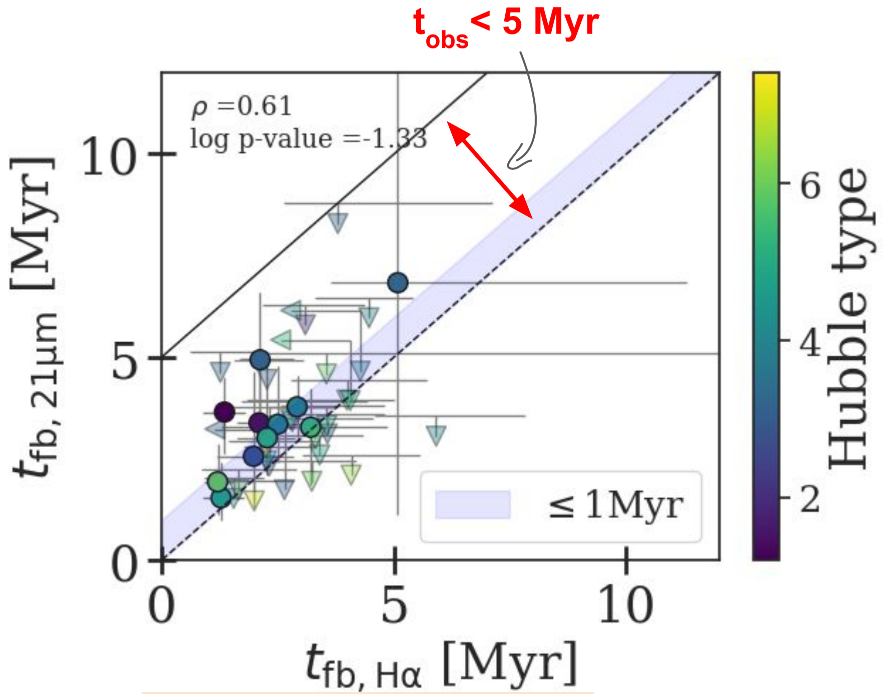
- The **embedded star-formation phase is short (<5 Myr)** in all the galaxies
- **< 1 Myr** for 28/37 galaxies.

III - Results : measuring the timescales associated with the dust-embedded SF

1. *Is the dust-obscured phase of star-formation short in all galaxies ?*

Ramambason et al. in prep

exposed+embedded star formation



exposed star formation

⇒ Feedback timescales consistent with **pre-supernova feedback (< 4 - 5Myr)**
e.g, Chevance+20,+22, Kim+21,+23

⇒ t_{obs} consistent with age estimates of **dust-embedded young stellar populations ~ 1 - 4 Myr**
e.g, Whitmore+15, Hollyhead+15, Grasha+18, Deshmuk+24, Sun+24, Rodriguez+25, Whitmore+25

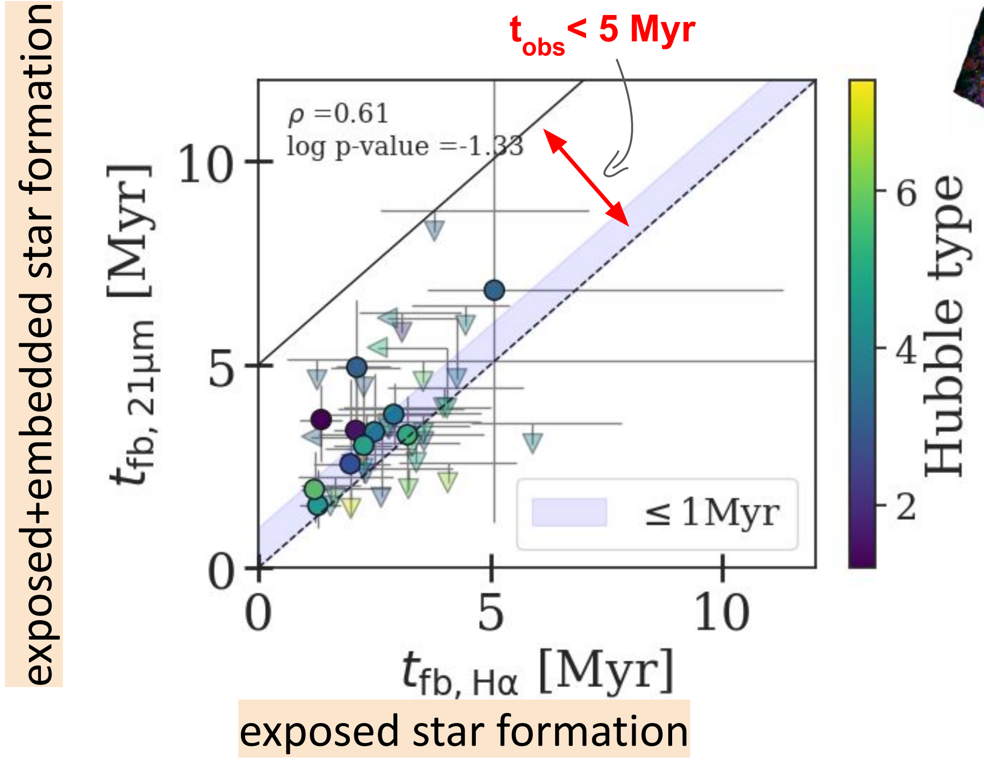
- simulations (e.g., STARFORGE)

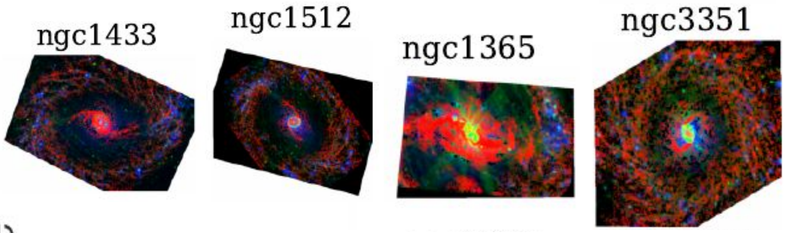
See Tobin Wainer's poster !

III - Results : measuring the timescales associated with the dust-embedded SF

1. Is the dust-obscured phase of star-formation short in all galaxies ?

Ramambason et al. in prep





Only galaxies with longer dust-obscured star-formation phase **barred spiral galaxies :**

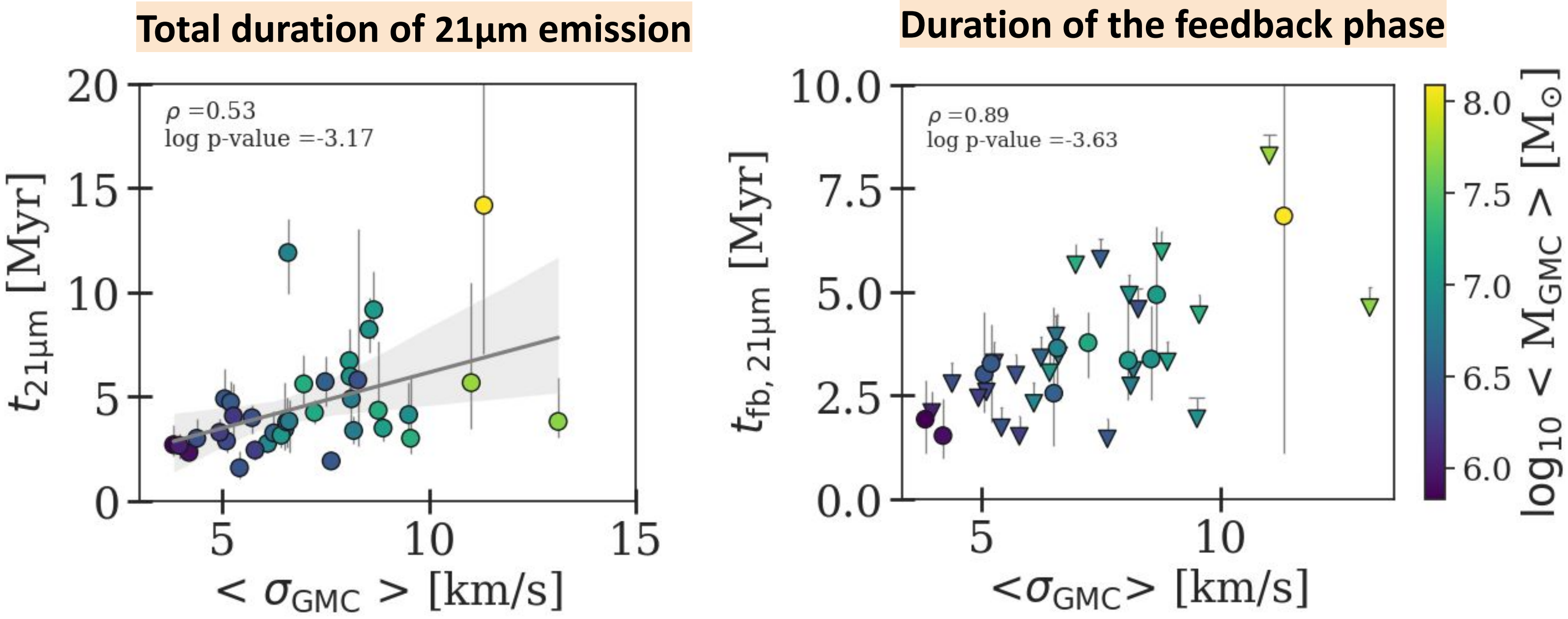
- **more gas-rich**
- **more metal-rich**

⇒ *statistical analysis of <u>all possible correlations</u> with global galactic properties and GMC properties*

III - Results : measuring the timescales associated with the dust-embedded SF

2. Which parameters regulate the duration of the dust emission at 21um ?

Ramambason et al. in prep



⇒ **Increased duration** of the 21µm emission and feedback phase in galaxies with :

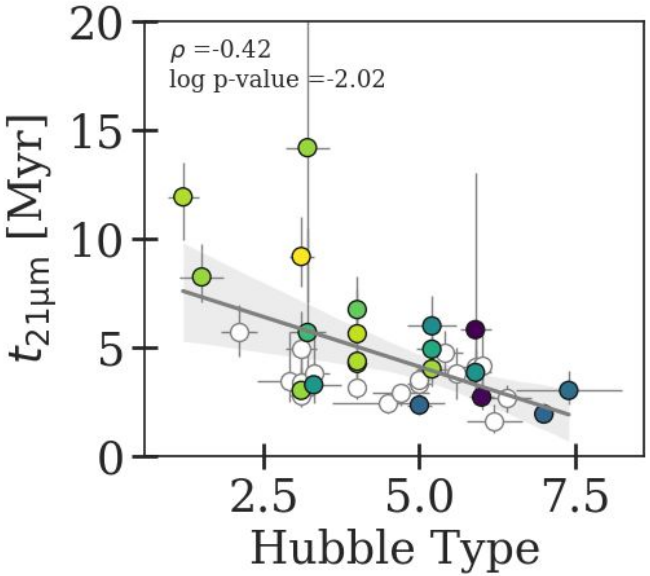
- more **massive GMCs**
- higher **velocity dispersion**

III - Results : measuring the timescales associated with the dust-embedded SF

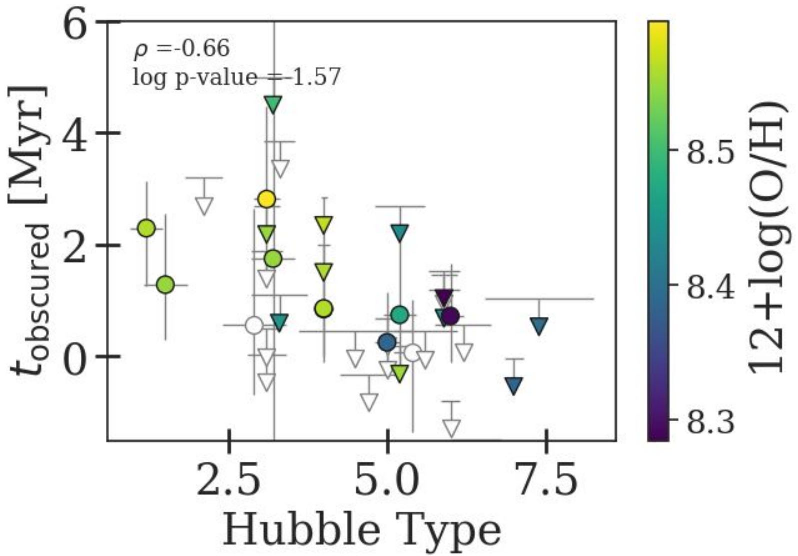
2. Which parameters regulate the duration of the dust emission at 21um ?

Ramambason et al. in prep

Total duration of 21µm emission



Duration of the dust-obscured SF phase



⇒ **Reduced duration** of the 21µm emission and dust-obscured star-formation phase:

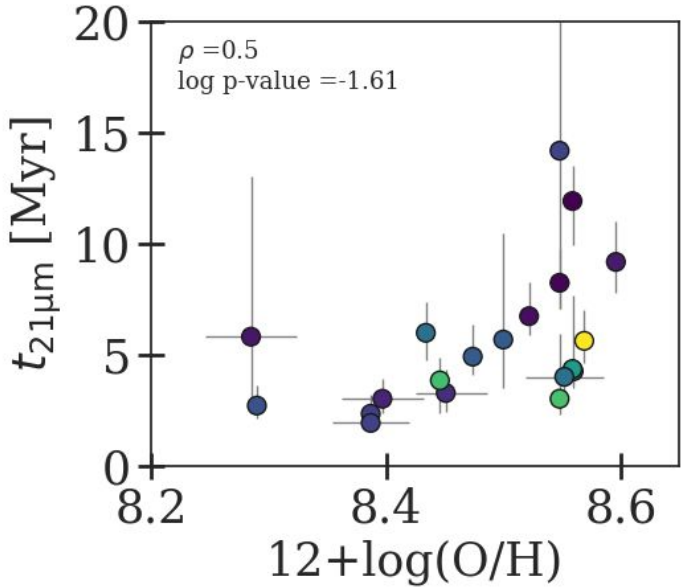
- later type galaxies (**flocculent and irregular morphologies**)
- smaller **metallicities**

III - Results : measuring the timescales associated with the dust-embedded SF

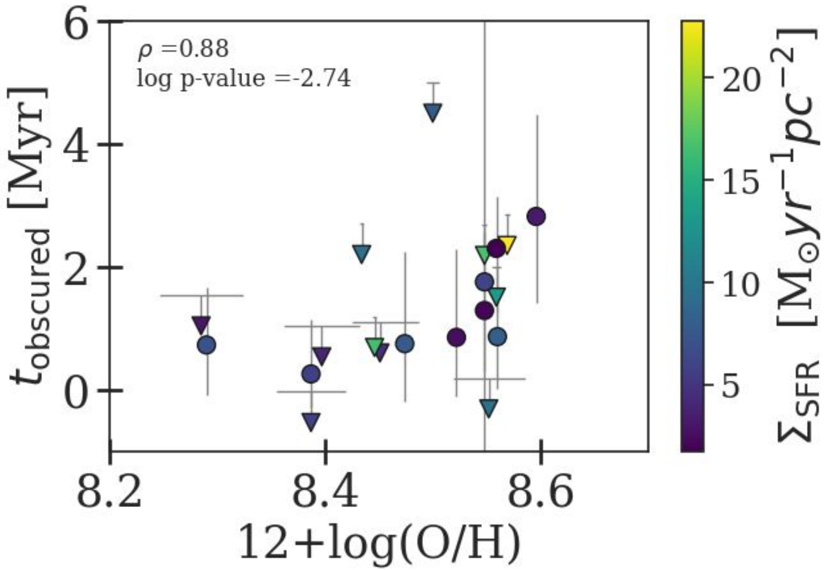
2. Which parameters regulate the duration of the dust emission at 21um ?

Ramambason et al. in prep

Total duration of 21µm emission



Duration of the dust-obscured SF phase



⇒ Tentative **increased duration of the 21µm emission and duration obscured SF phase in galaxies with <u>higher metallicity.</u>**

⇒ **ionization mechanisms dominant** over stellar winds ?

Summary

- **The dust-obscured star-formation phase is typically very short (< 1 Myr)**

- Feedback timescales hint at a predominant role from **pre-SN stellar feedback (< 4 - 5 Myr)**

- The 21µm timescales and timescale of embedded SF phase vary with:

  - GMC-averaged properties
  - global galactic properties
  - metal and dust content

Summary

- **The dust-obscured star-formation phase is typically very short (< 1 Myr)**
- Feedback timescales hint at a predominant role from **pre-SN stellar feedback** **(< 4 - 5 Myr)**
- The 21µm timescales and timescale of embedded SF phase vary with:

  - GMC-averaged properties
  - global galactic properties
  - metal and dust content

… and prospects !

⇒ **Multiscale :**

- Scatter around **galaxy averages**
- Connections with **HII regions** and **stellar population** scales

⇒ **Multiwavelength :**

- more tracers : e.g., **dense gas tracers**
- **CO resolution is limiting** but not easy to replace

⇒ **Evolving (with redshift) :**

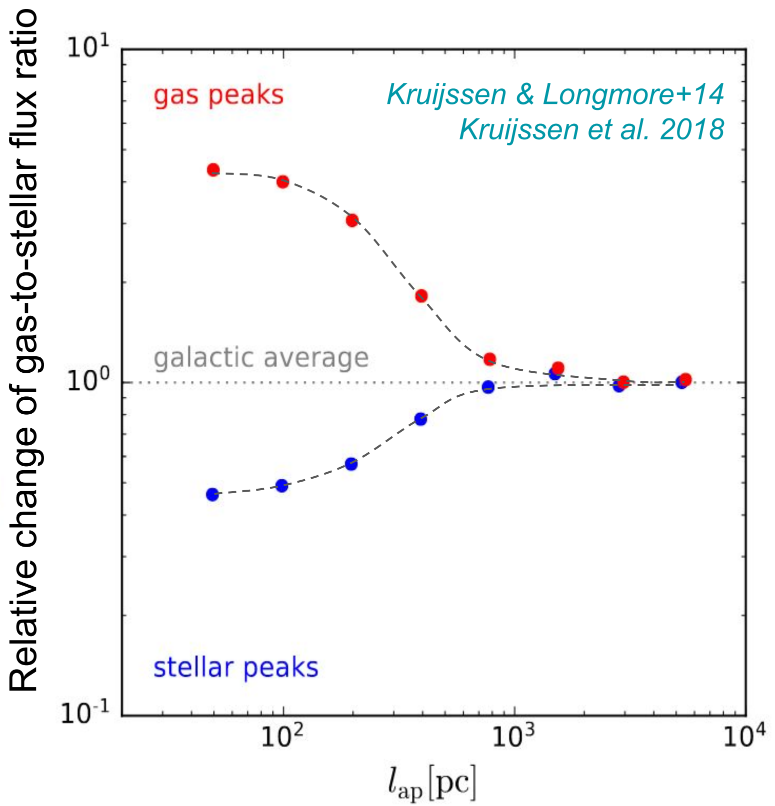
- explore the **low-metallicity regime**

(e.g., PHANGS-dwarf , Egorov et al .in prep)

Fitting tuning-forks (3 free parameters) from Kruijssen & Longmore+14

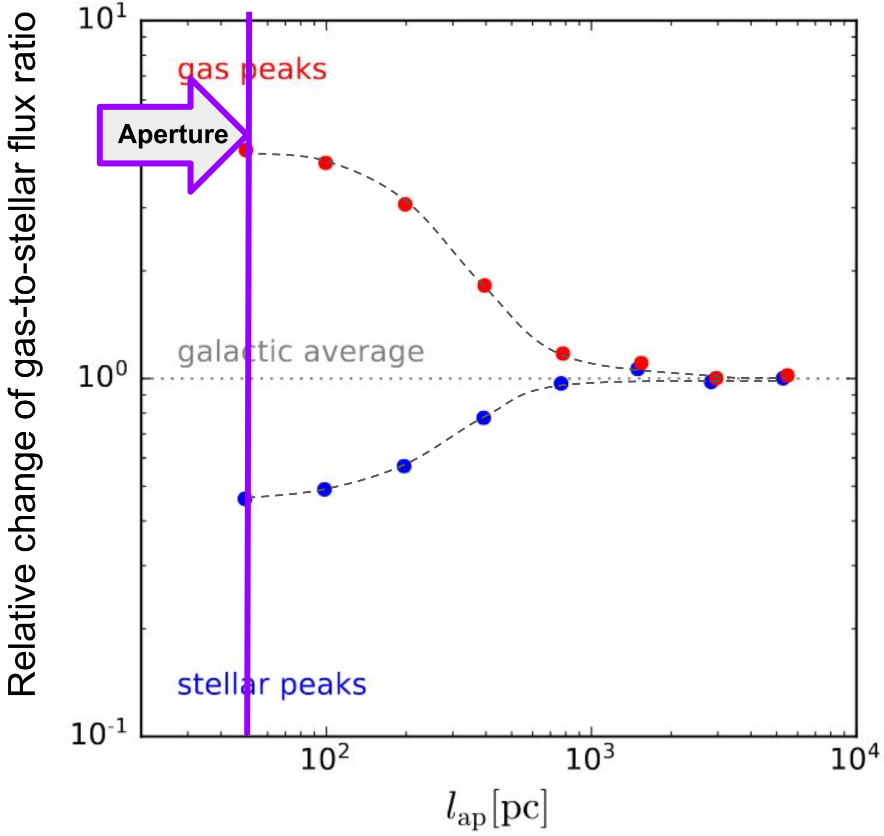
$$\frac{[t_{\rm depl}]_{\rm gas}}{[t_{\rm depl}]_{\rm gal}} = \frac{1+\frac{t_{\rm gas}}{\tau}\left(\frac{l_{\rm ap}}{\lambda}\right)^2}{\beta_{\rm s}\frac{t_{\rm over}}{t_{\rm star}}\left[1+(\beta_{\rm s}-1)\frac{t_{\rm over}}{t_{\rm star}}\right]^{-1}+\frac{t_{\rm gas}}{\tau}\left(\frac{l_{\rm ap}}{\lambda}\right)^2}, \quad (15)$$

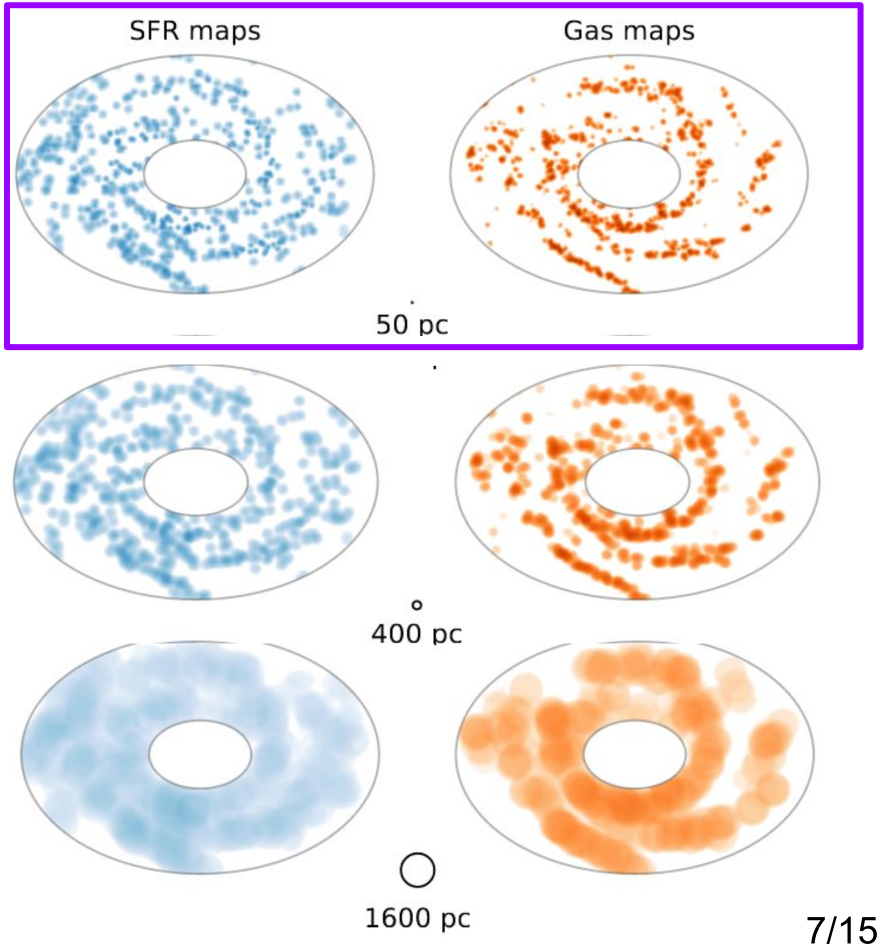
$$\frac{[t_{\rm depl}]_{\rm star}}{[t_{\rm depl}]_{\rm gal}} = \frac{\beta_{\rm g}\frac{t_{\rm over}}{t_{\rm gas}}\left[1+(\beta_{\rm g}-1)\frac{t_{\rm over}}{t_{\rm gas}}\right]^{-1}+\frac{t_{\rm star}}{\tau}\left(\frac{l_{\rm ap}}{\lambda}\right)^2}{1+\frac{t_{\rm star}}{\tau}\left(\frac{l_{\rm ap}}{\lambda}\right)^2}. \quad (16)$$



III- 2. The tuning-fork method: exploiting spatial correlations between stars and gas

Kruijssen & Longmore+14
Kruijssen et al. 2018





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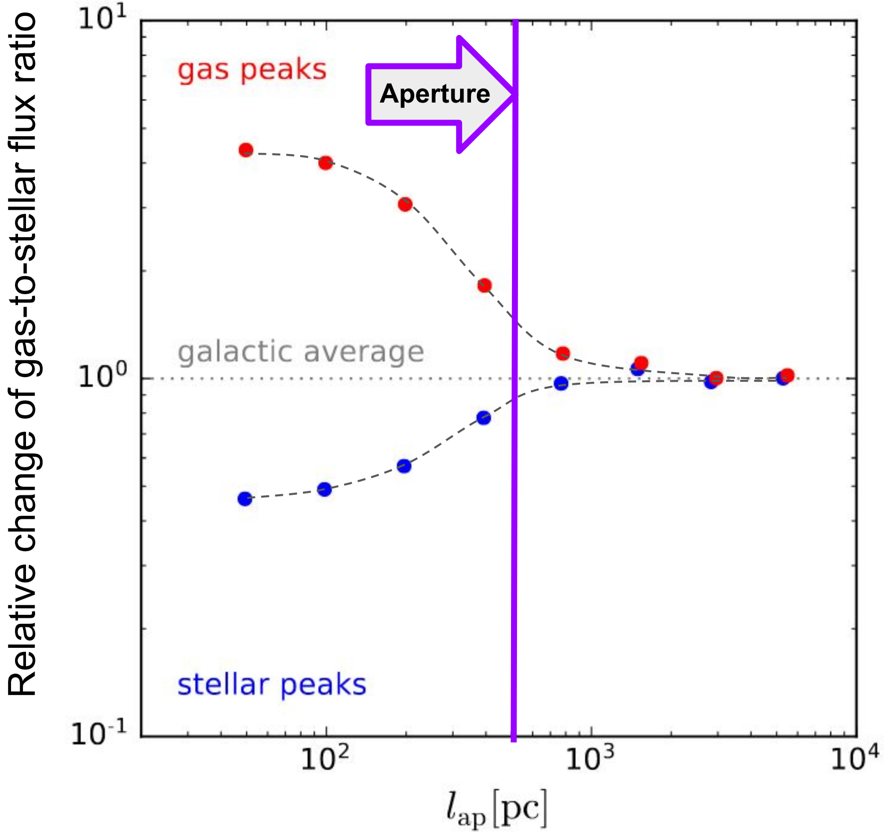

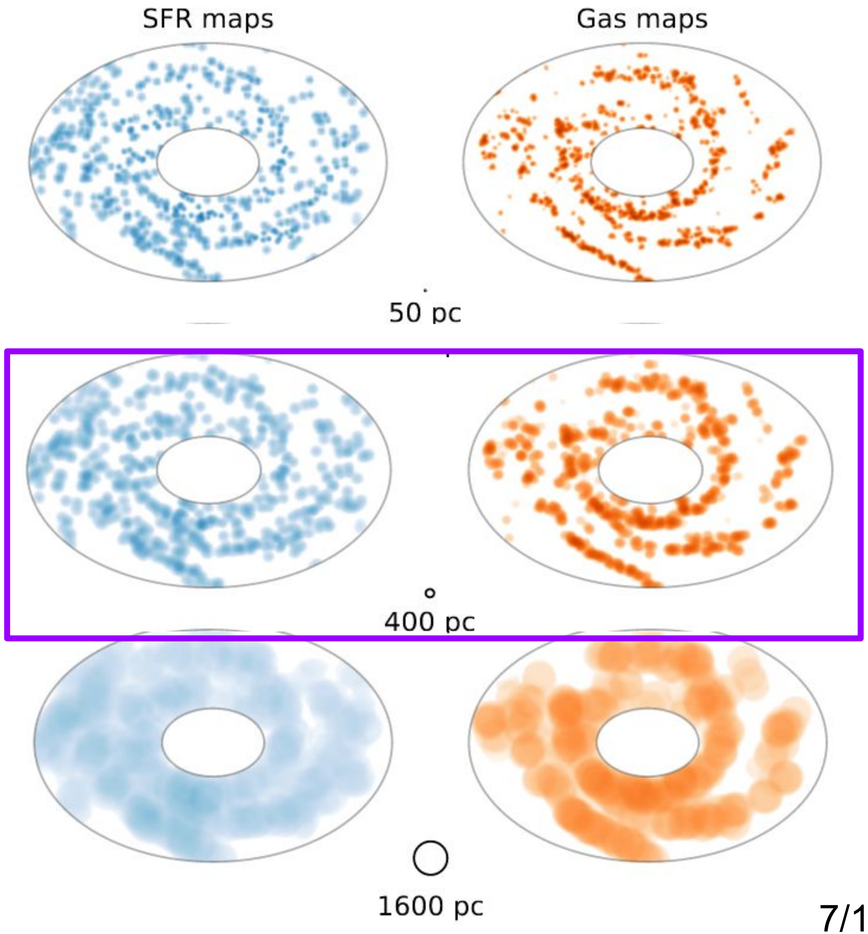

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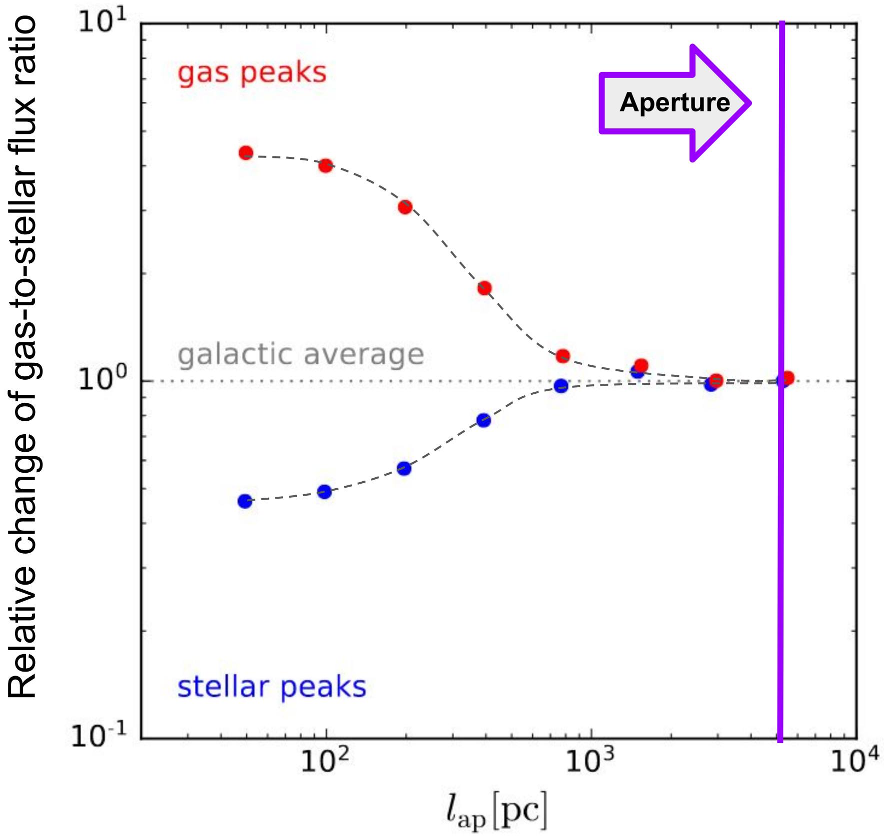
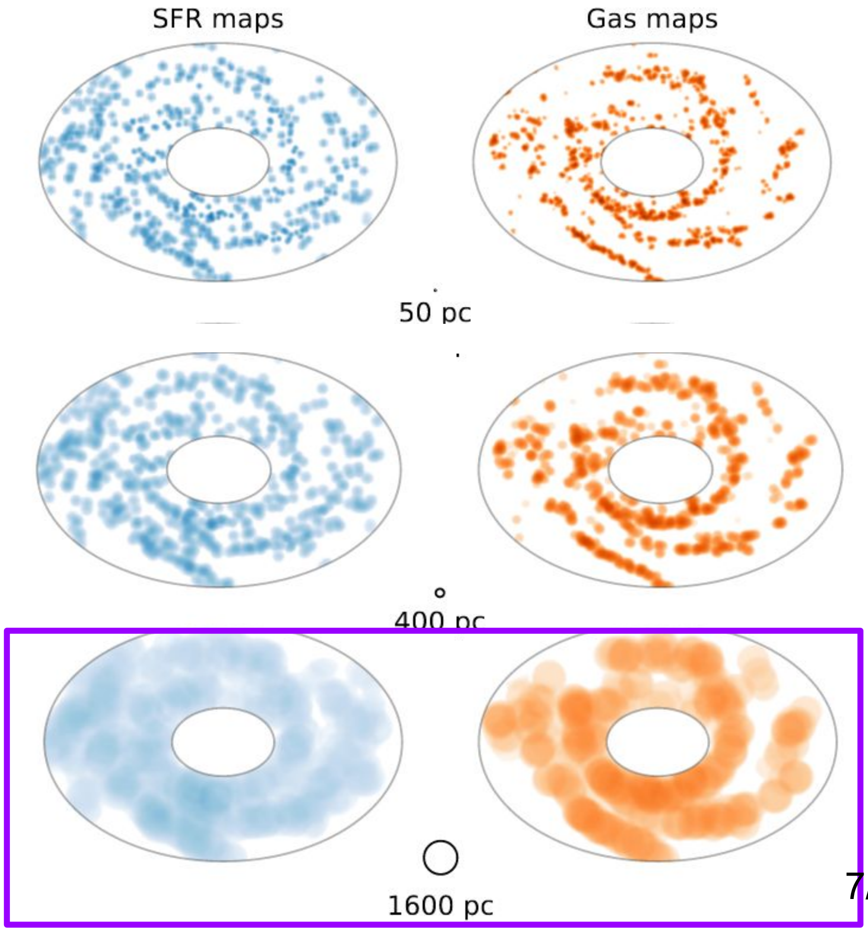
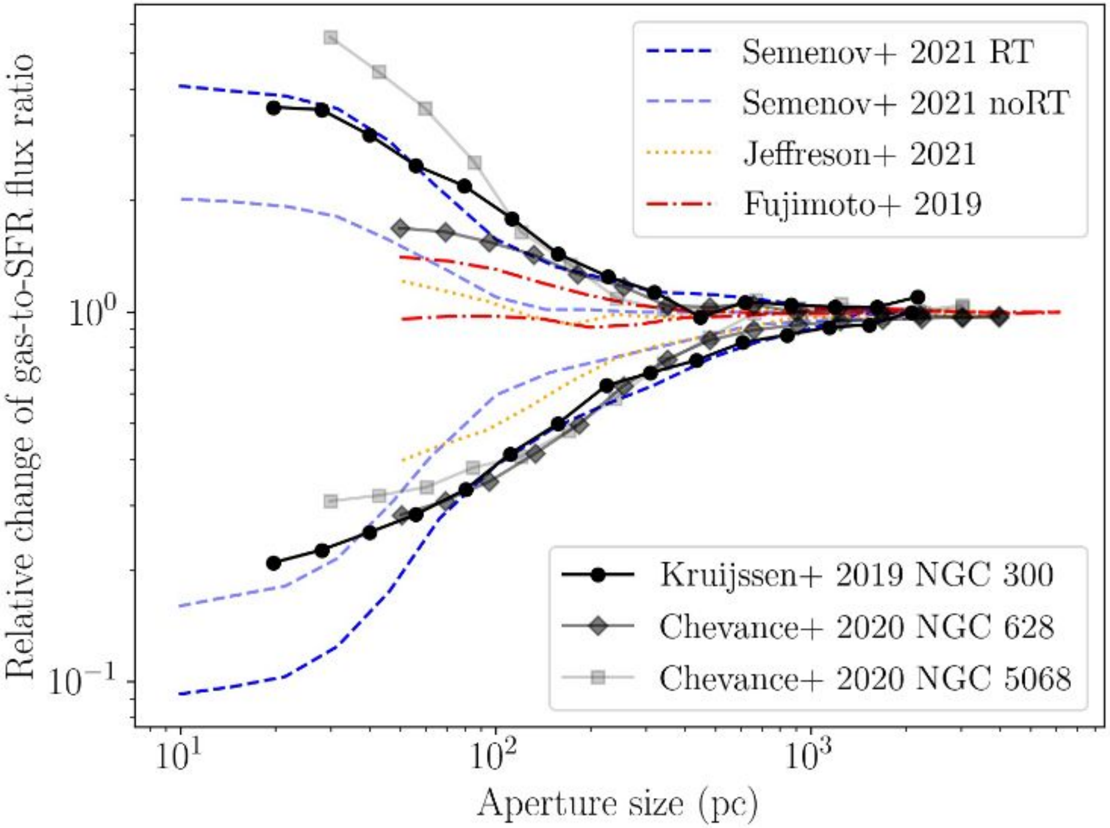




Reproducing gas/star de-correlation in simulations



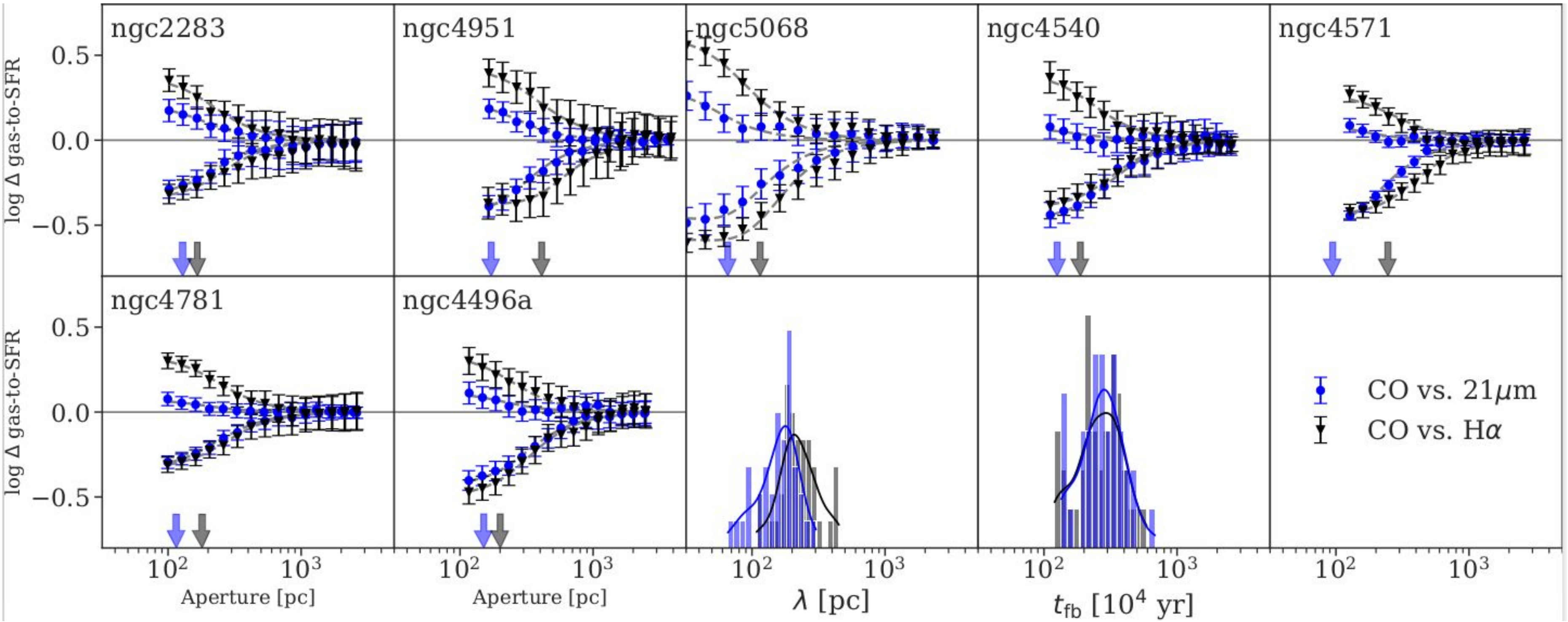
Chevance et al. 2023, PPVII review

Morphological T type (Paturel+98)

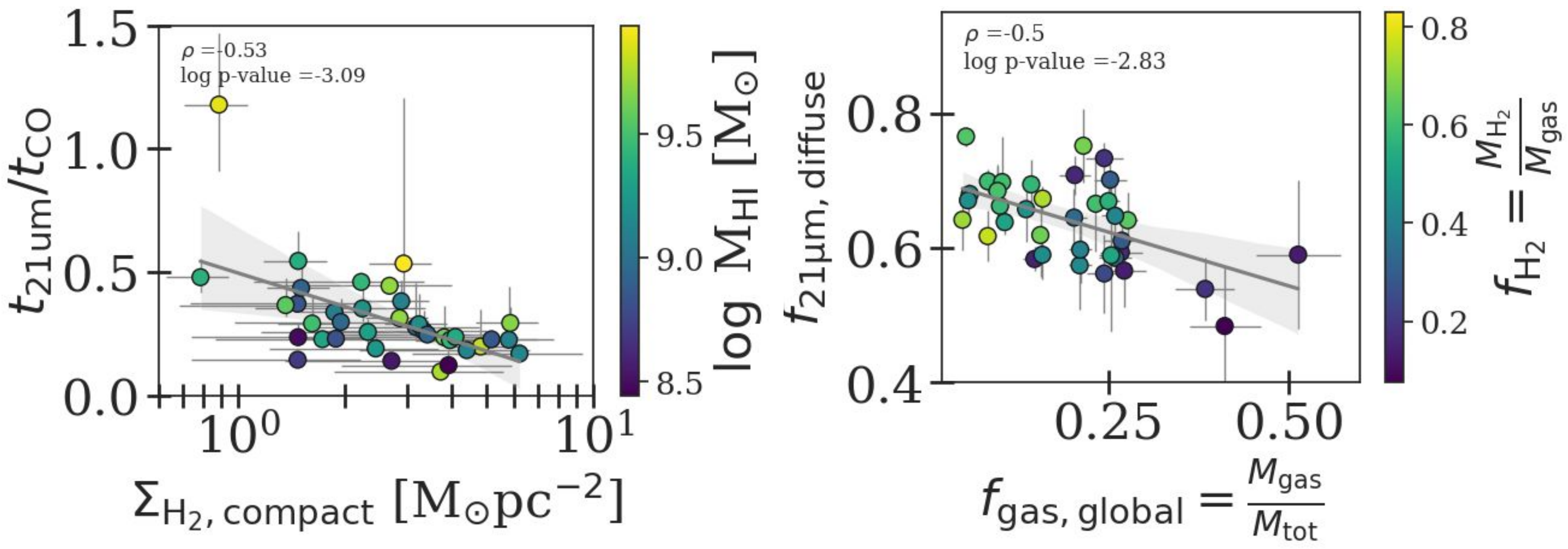
range of t	typ	range of typ	type
$-5 \leq t < -3.5$	E	$3.5 \leq t < 4.5$	Sbc
$-3.5 \leq t < -2.5$	E-SO	$4.5 \leq t < 6.5$	Sc
$-2.5 \leq t < -1.5$	SO	$6.5 \leq t < 7.5$	Scd
$-1.5 \leq t < 0.5$	SOa	$7.5 \leq t < 8.5$	Sd
$0.5 \leq t < 1.5$	Sa	$8.5 \leq t < 9.5$	Sm
$1.5 \leq t < 2.5$	Sab	$9.5 \leq t < 10$	Irr
$2.5 \leq t < 3.5$	Sb		

Table 3. Output morphological type codes

Smaller decorellation scale when using 21um vs Ha as SFR tracer

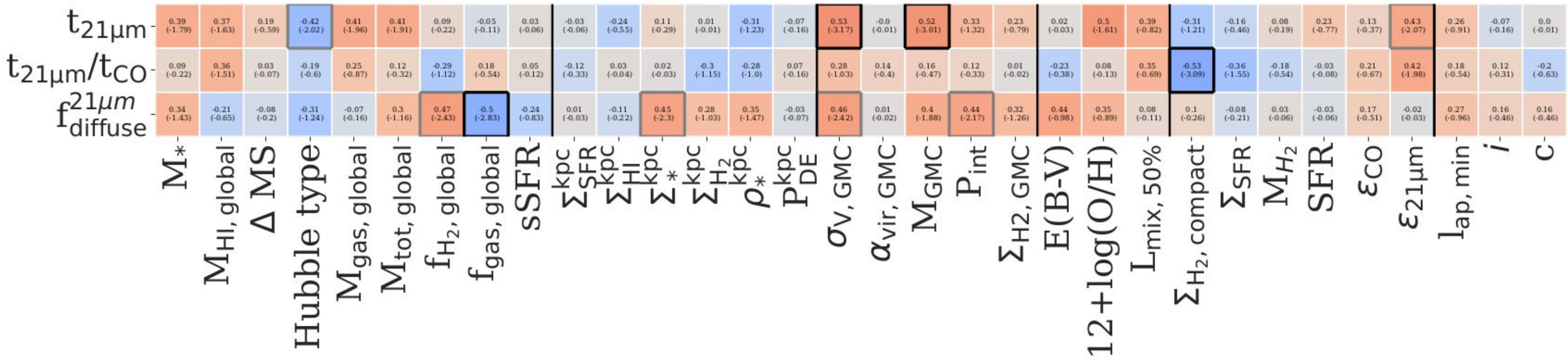


Additional correlations



Correlations using the Holm-Bonferroni method

$$p_{\mathrm{eff}} = \frac{p_{\mathrm{ref}}}{N_{\mathrm{corr}} + 1 - i}$$



Global parameters | **kpc-scale** | **GMC-scale** | **HII region** | **Heisenberg** | **Systematics**